Predicting Standard Penetration Test (SPT-N) Value from Electrical Resistivity Result

By

Mohamed Ashnor Bin Mohamed Raffek
17618

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
Civil

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Universiti Teknologi PETRONAS
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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Syed Baharom Azhar Syed Osman)

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Sept 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MOHAMED ASHNOR BIN MOHAMED RAFFEK

ABSTRACT

Soil investigation is the first stage of the process in order to obtain the parameter of the soil and also to understand the behavior of the subsoil before building any civil structure. It is important for optimizing the cost and to avoid from overdesigning of the foundation. Standard Penetration Test is the conventional and destructive method currently being used to obtain the soil profile of the tested site in order to obtain the parameter and characteristic of the soil. This research is to study and to obtain correlation of electrical resistivity and SPT-N from Standard Penetration Test (obtain from seismic wave method) of subsurface soil from selected sites. Obtaining the SPT-N value from electrical parameters have least been researched by scholars. Electrical resistivity is a non-destructive method, very sensitive and able to capture and describe the properties of the subsoil without disturbing the original physical characteristic of the soil. This research work involves field work which was conducted at five different randomly selected area. Laboratory work was also carried out in this research in order to obtain the basic properties of the soil such as plasticity index, particle size distribution, moisture content and laboratory electrical resistivity. Results indicate that as the inverted electrical resistivity increases, the SPT-N (Seismic) value of the soil will increase with a moderate linear correlation (R^2 = 0.6973). While in the relationship between moisture content and inverted electrical resistivity, it shows a moderate non-linear relationship with regression number of (R^2 = 0.5448). Increases in moisture content of the soil will results in decreases of inverted electrical resistivity due to the behavior of moisture that has high conductivity to the electrical current. Besides, the relationship between moisture content and SPT-N (Seismic) shows a non-linear relation with regression number of (R^2 = 0.6216). The result shows, increases of moisture content will results in decreases of SPT-N value. So it can be concluded that varied value of electrical resistivity of the soil enable to predict the SPT-N value which is important to get the overview and the properties of the subsoil surface.

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First and foremost, I would relish to take this opportunity to express my greatest appreciation to all the parties who had contributed during the past eight months for my final year project. Heartfelt thanks to my FYP supervisor, Dr Syed Baharom Azhar Syed Osman for most of the time in the effort that he has spent and devoted to me as well as his illimitable patience and thoughtfulness in guiding me throughout my final year project.

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INTRODUCTION

1.1 Background of Study

Geotechnical site investigation (SI) is the mandatory process in order to obtain the geotechnical parameters of earth materials which is fundamental for the purpose of constructing high rise buildings, roads, bridges and engineering structure. Site investigation is conducted to evaluate the general suitability of constructing any structure on soil by generating some view of the ground strata and the properties of soil. Standard penetration test (SPT) is one of the method that is currently being used in soil investigation in order to obtain strength parameter in the design of many geotechnical structures. Soil penetration resistance from SPT is the essential parameter which gives angle of friction, cohesion, relative density etc. of the soil.

In 1912, Schlumberger brothers (Conrad Schlumberger and Marcel Schlumberger) were the first to discover the basic concept of field electrical resistivity. The earlier industries that implemented the electrical resistivity method were mining and petroleum. Some of the researcher has discovered that it is an effective method in order to get the view of underneath profile in geotechnical investigation (Samouëlian et al. 2005). Electrical geophysical is a non-destructive, time saving and cost-effective method that enable to obtain the resistivity of a soil (Hatta & Syed Osman, 2015). The soil are divided into three phases of heterogeneous materials which consists of solid, liquid and gases (Hatta & Syed Osman, 2015). Based on soil electrical properties, it enable the engineers to predict the subsoil layer based on the soil resistivity. Electrolytic action is the main causes of the current flow through the soil and therefore it is depends on the concentration of dissolved mineral salts in the pores of soil where typical values are given.

1.2 Problem Statement

The concern on the soil failure due to bearing capacity that will result in sinking and collapse of civil engineering structure poses a threat to the general public. Due to this, geophysical investigation and deep knowledge on the properties of the sub surface soil in any project work location is very essential. This provide the geotechnical engineer with necessary understanding of the soil strata and obtaining parameter for the purpose of geotechnical design.

In geotechnical investigation, conventional borehole method is still considered to be the most reliable method in acquiring strength parameter. However, it requires huge equipment and it is not practical to be move from one project site to another especially when the project site has limitation on accessibility such as at the mountainous or rural area. By conducting conventional method it required high budget in costing since it uses a heavy equipment and required more expertise to conduct the test. Besides, it is consider as a destructive method because by conducting the Standard Penetration Test, it require soil boring and it will cause the physical characteristic of the soil or the original structure of the soil to be disturb.

Other drawback of the conventional method of soil investigation is time consuming, it required some time to set up the bulky equipment and to transport the equipment to the investigation site. By utilizing the electrical resistivity method it enable to predict the SPT-N value and it allow the geotechnical engineer to obtain a clear picture and information of the subsurface on the area that being working on.

1.3 Objective

To study and obtain correlation of electrical resistivity and SPT-N from Standard Penetration Test (obtain from surface wave method) of subsurface soil from selected site.

1.4 Scope of Study

The scope of study was divided into three (3) stages which are studies on the literature review, field work which include (electrical resistivity test and seismic wave survey to obtain SPT-N value), and lab test. On the first stage, studied on the literature review by previous researcher has been done in order to gained some point of view on this study. On the second stage, field work has been proceed at several places in order to carry out electrical resistivity and standard penetration test (surface wave method). At the last stage, several basic tests such as Atterberg limit (plastic limit and liquid limit), moisture content, particle size distribution and laboratory electrical resistivity tests were also performed to obtain the basic parameters of the respective soil.

CHAPTER 2
LITERATURE REVIEW

2.1 Standard Penetration Test (SPT)

Standard Penetration Test is one of the most established in-situ testing that being applied by the engineer on evaluating the properties of soil (Bery & Saad, 2012). The method of the test is based on the American Society of Testing and Materials (ASTM), in ASTM D 1586: Standard Test Method for Penetration Test and Split Barrel Sampling of Soils (Rogers, 2006). Split barrel sampling unit which known as "split spoon sampler" is hammer to a distance of 18 inches into the undisturbed soil with a free-fall weight of 140 pound (63.5kg).The weight are being fall with a constant height of 30 inches (760mm) and each of the hammer strike is recorded through three consecutive of 6 inches (152mm) interval (Rogers, 2006).

In the first interval, the sampler are allowed to penetrate at any disturb soil that caused by drilling which known as seating interval. In order to determine the soil condition and properties, it is possible to be obtained by evaluating the N-value which is known as blow count (summation of hammer strikes in the final interval). The test is stopped and the sampler is thought to have achieved refusal when any interval 50 blows is preceding to advancing the sampler 6 inches. Due to the extensive database of recorded testing, standard penetration test are consider as the essential field method and it allow the engineer to get the information on the subsoil layer. Due to budget and equipment constraint, in this study the standard penetration test (N-value) are obtain by converting the seismic wave method result.

There are a few confinements for these tests. First, numerous corrections are required for interpretation and design. Second, it is influenced by borehole disturbance, for example, piping, base heave and stress relief. Lastly, it is influenced by large, huge and bulky equipment to make borehole and by operator (Bery & Saad, 2012). Thus, in this study we did other appropriate method to lessen the constraints which might give the data standard penetration test and subsurface condition. For our first exertion, in this study we attempt to utilize electrical resistivity method to determine the relationship in between these two methods for environmental engineering applications.

Soil Type and SPT Blow Counts		Undisturbed Soil	
		Cohesion (psf)	Friction Angle (°)
Cohesive soils			
Very soft	(<2)	250	0
Soft	(2–4)	250–500	0
Firm	(4–8)	500–1,000	0
Stiff	(8–15)	1,000–2,000	0
Very stiff	(15–30)	2,000–4,000	0
Hard	(>30)	4,000	0
Cohesionless soils			
Loose	(<10)	0	28
Medium	(10–30)	0	28–30
Dense	(>30)	0	32
Intermediate soils			
Loose	(<10)	100	8
Medium	(10–30)	100–1,000	8–12
Dense	(>30)	1,000	12

Table 2.1: Estimated values of soil cohesion and friction based on uncorrected Standard Penetration Test (David, 2006).

2.2 Geophysical Investigation – Electrical Resistivity Method

In engineering applications, geophysical testing is utilized to help in describing and interpreting near surface conditions. Near surface is for the most part thought to be depth less than 30 meters (Butler & Dwain, 2005; Hubbard, 2009).

Case of uses include: investigation of lithology, assessment of karst conditions and faulting, determination groundwater level, mapping of bedrock, determination thicknesses on material layer, area of development materials, observing of dams or levee strength and determination in classification of seismic site (Hubbard, 2010; Steeples, 2001). The determination of method is depends on the studied area, required determination, spending limitations and existing geologic and social conditions.

There are several types of geophysical method in soil investigation such as electrical resistivity, seismic, gravitational testing, and magnetic methods of which testing methods can either be conducted from the surface or in downhole arrangements (Hubbard, 2010). The utilization of various techniques can give an improved understanding of the site and the sought quantifiable property at a given site (Steeples, 2001). For the purpose of this study, the discussion of geophysical testing method will concentrate on the analysis and measurement of electrical resistivity of the soil.

2.2.1 Background of Electrical Resistivity

Resistivity distribution of the subsoil surface can be determine by electrical resistivity surveys and Wenner array will be implemented throughout this study. Artificial electrical current from D.C (Direct Current) power source are ejected to the soil resulting in measurement on potential difference. Electrical resistivity method has been introduced by Schlumberger brother in 1920. By conducting this method it enable us to get clear picture in resistivity distribution on the subsoil surface. This method was first implemented for searching of oil reservoirs and study the formation of geological underneath by oil and gas companies. The uses on the electrical resistivity were widely expand in geotechnical investigation after the equipotential map was compiled by Malamphy for archeology research in 1938 (Bevan, 2000; Samouëlian et al., 2005).

Electrical resistivity survey enable to image the changes of an electrical resistivity of soil with increase in depth and also able to detect the location of water-saturated clay, which can be defined as low resistivity zone (Abidin et al., 2012). In general there are many factor that will affect the electrical resistivity of the soil. One of the major factor that will drastically shows the effect on electrical resistivity is moisture content of the soil and it has been prove from laboratory test between the moisture content and electrical resistivity of the soil on Figure 2.2 (Samouëlian et al., 2005). From the results it shows that resistivity increase rapidly while with decreasing of moisture content.

Decreasing rate of electrical resistivity reduces substantially at moisture contents in excess of 15%, and to a minimum for moisture content in excess of 20%. This evidence has been support with investigating the relationship of water content and electrical resistivity on compacted clay as shown in Figure 2.3 (Kibria & Hossain, 2012). Other factor that also significantly affect the resistivity of soil such as degree of saturation, porosity, void structure and electrical resistivity of the pore fluid (Hatta & Syed Osman, 2015). Soil temperature, salinity and texture are also will contribute in affecting the electrical resistivity of the soil (J.-J. Zhu et al., 2007).

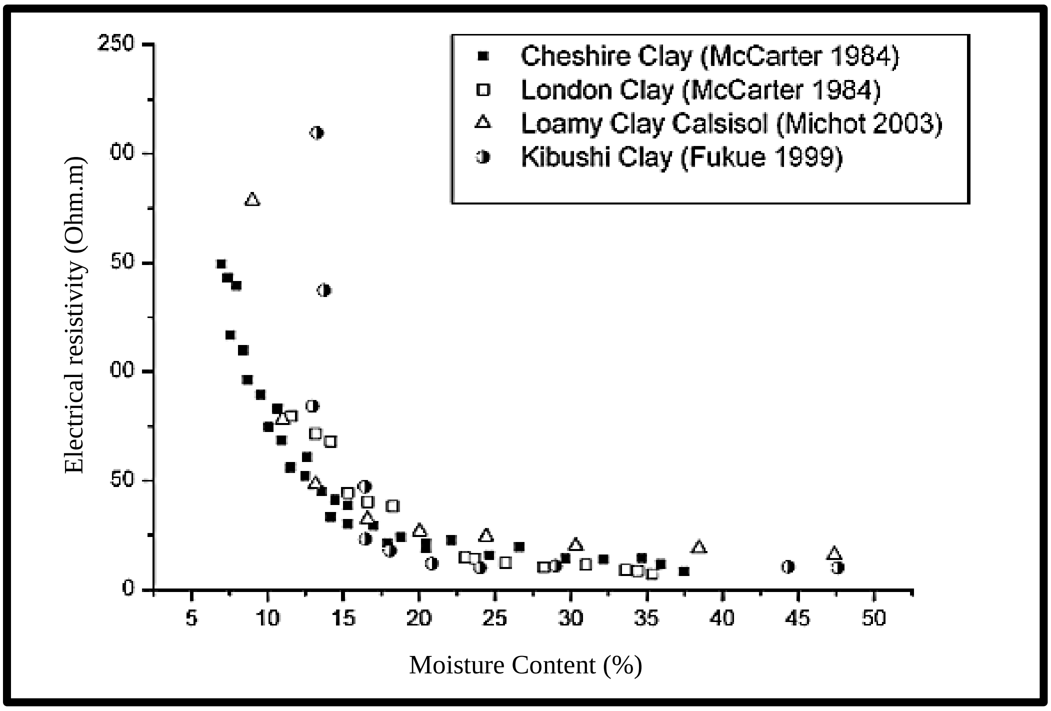


Figure 2.2: Relationship of moisture content and electrical resistivity for different type of soil (Hatta & Syed Osman, 2015)(Samouëlian et al., 2005)

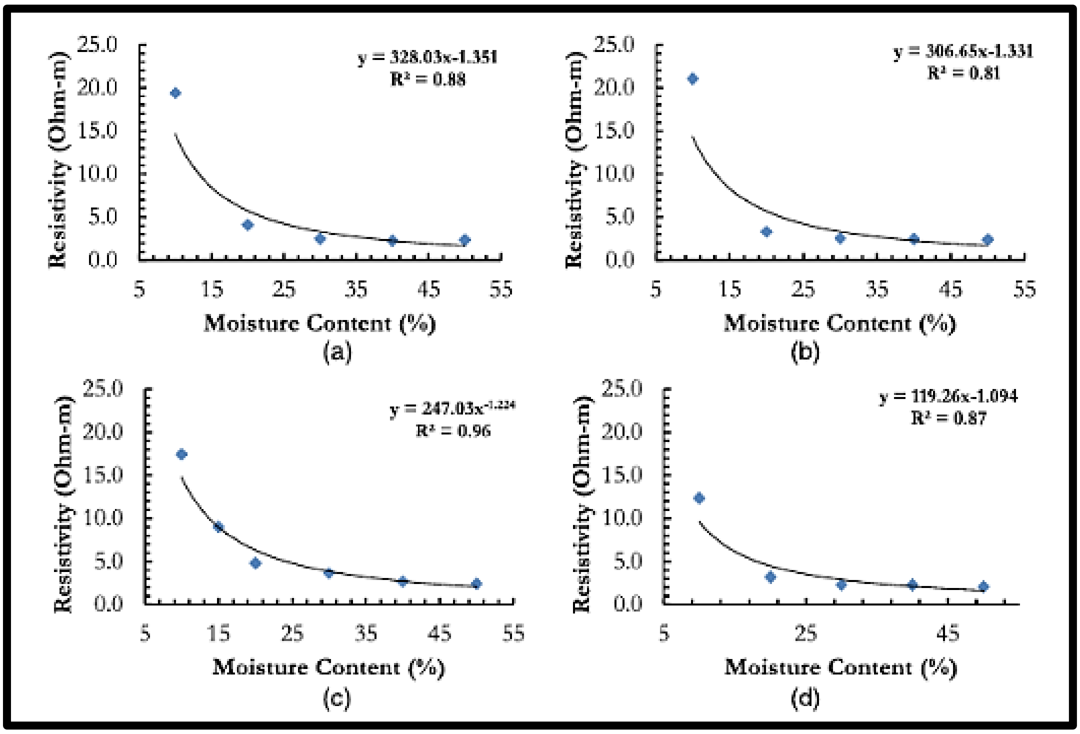


Figure 2.3: Variation of soil resistivity with moisture content (Kibria & Hossain, 2012)

The matrix of soil are composed of solid material which can be occupy by water, air or organic contamination (Hubbard, 2009). A void that been filled by water table has low in resistivity compare to the surrounding rocks while void that been filled air has high resistivity compare to geologic materials (J. Zhu, Currens, & Dinger, 2011). Soil is relatively non-conductive to electricity if there is no mineral bodies and clay particles. For that reason degree saturation and porosity of soil give an essential role in measuring the soil electrical resistivity.

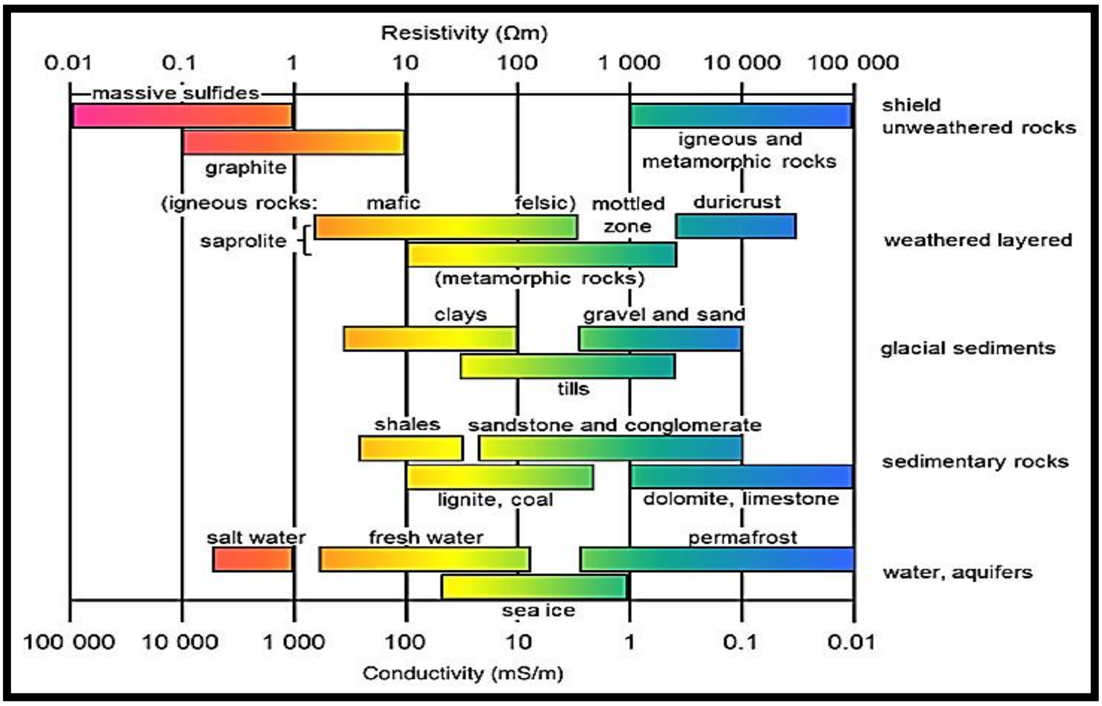


Figure 2.4: Typical ranges of electrical resistivity and conductivity of earth material (Samouëlian, Cousin, Tabbagh, Bruand, & Richard, 2005)

2.2.2 Variation of electrical resistivity as a function of soil properties

The electrical resistivity is an element in determining various soil properties, including the way of the solid constituents (mineralogy, particle size distribution), level of water saturation (moisture content), arrangement of void (porosity, pore size distribution), temperature, and electrical resistivity of the liquid (solute concentration) (Samouëlian et al., 2005). The water solution resistivity is an element of the ionic concentration, the air medium is an insulator, and the resistivity of the solid grains is identified with the electrical charges density at the surface of the constituents. These parameters influence the electrical resistivity of the soil, however in various courses and to various degrees. Electrical resistivity tests have been performed to set up coloration between the electrical resistivity and each of these soil parameter.

2.2.3 Theories on Electrical Resistivity

Potential difference distributions delivered information in the form of electrical and heterogeneous properties (solid, liquid, gas) (Samouëlian et al., 2005). Electrical resistivity of the soil can be considered as an intermediary for the variability of soil physical properties (Samouëlian et al., 2005). Distribution of current flow depending on the subsoil layer (medium) of the study area. For a simple body, the resistivity (Ω m) is defined as follows (Hubbard, 2010; Samouëlian et al., 2005):

$$\rho = R\left(\frac{S}{L}\right)$$

R is the electrical resistance (Ω), S is the cross-sectional area (m^2) and L is the length of the cylinder (Samouëlian et al., 2005). By using Ohm's Law, the electrical resistance of cylindrical body can be defined as follows (Hubbard, 2010):

$$R = \frac{V}{I}$$

I being the current (A) and V is the potential (V). Electrical characteristic is defined by the conductivity value σ (Sm^{-1}), which is equal to the inverse of the soil resistivity (Samouëlian et al., 2005):

$$\sigma = \frac{1}{\rho}$$

When the current electrodes are ejected in the surface of soil, the electrical equipotential distribution are in the hemispherical manner throughout the homogeneous soil as show in Fig. 2.2.1 (Samouëlian et al., 2005) .Current density J ($\mathrm{A/m}^2$) are calculated for all radial directions. Thus:

$$J = \frac{1}{2\pi r^2}$$

Surface of a hemispherical, $2\pi r^2$ is defined. Potential V are expressed as follows:

$$V = \frac{\rho I}{2\pi r}$$

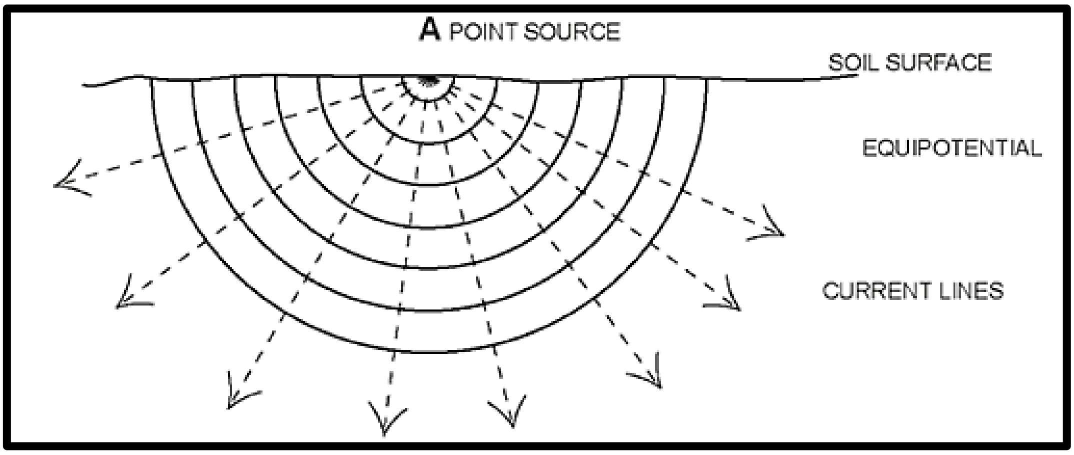


Figure 2.5: Distribution of the current flow in a homogeneous soil (Samouëlian et al., 2005)

2.2.4 Wenner Array

The Wenner array is the arrangement of the four electrodes with equal spacing. In order to detect the resistivity of soil it requires an electrical current to be injected into the ground by using electrode (J.-J. Zhu et al., 2007). As a consequence it offers a pattern with strong horizontal layering immediately below the potential electrode pair due to the sensitivity pattern of array. Even though in a noisy environment, the strong signal that is one of the criteria of Wenner Array enable it to capture the information (Pelton, & John, 2005). The resistivity measurement of Wenner Array can be defined from the Eq. (Hubbard, 2010).

$$\rho_\alpha = (2\pi\alpha)\frac{V}{I}$$

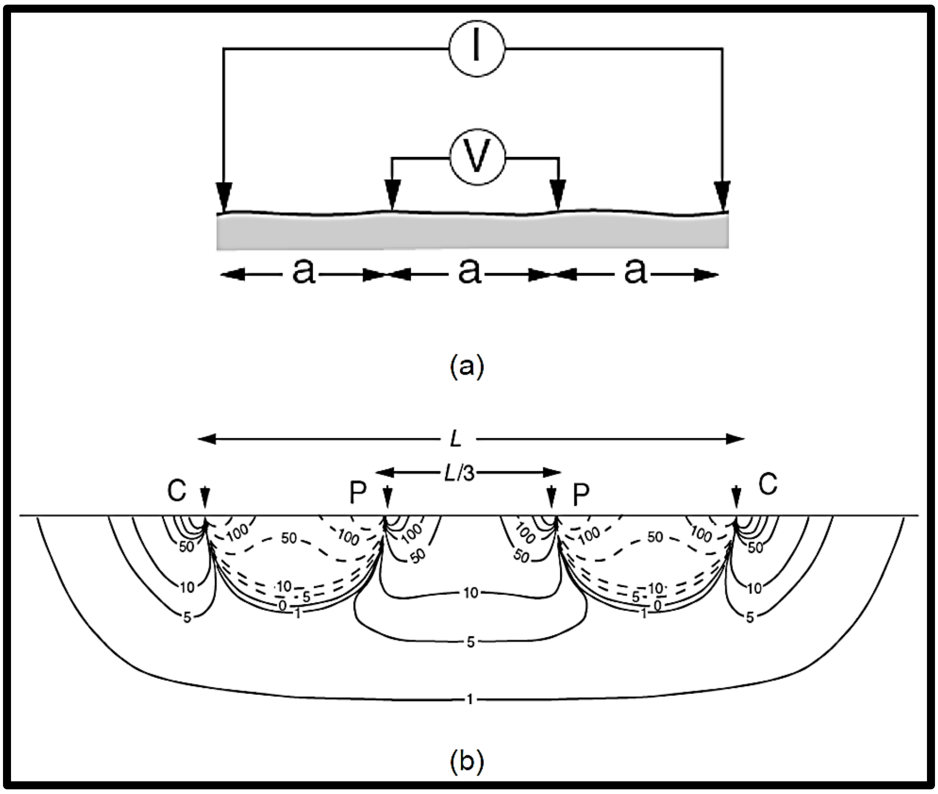


Figure 2.6: (a) Wenner Array Layout (b) Sensitivity Pattern of Wenner Array (Hubbard, 2010)

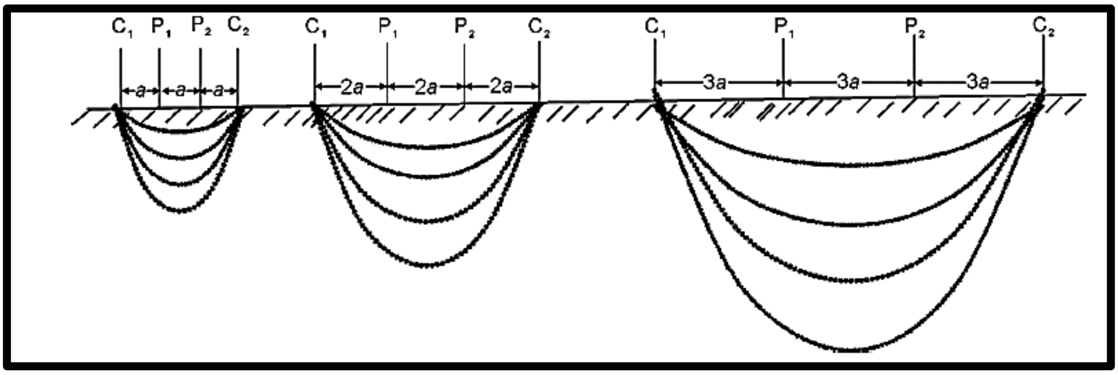


Figure 2.7: Measurement of soil resistivity for different intervals of soil depth by expanding the interelectrode interval (C1, C2, P1, and P2 are electrodes) (J.-J. Zhu, Kang, & Gonda, 2007).

2.3 Geophysical Investigations – Seismic Wave

In 1983 Nazarian and Stokoe has introduced a surface-wave method known as spectral analysis of surface waves (SASW) which enable to analyzes the dispersion curve of ground roll to produce near-surface S-wave velocity profiles. In order to obtain the information of the soil parameter as well as the characteristic SASW has been widely applied to many engineering projects(Uma Maheswari et al., 2009) .Due to utilizing of a single pair of receivers, SASW is not appropriate method when considering of time consuming for field survey.

After done some research project, finally Kansas Geological Survey introduced the most efficient method that enable to obtain an accurate result to estimate near shear wave velocity from ground roll which known as Multichannel Analysis of Surface Waves (MASW) (Uma Maheswari et al., 2009).Among all the type of seismic wave, surface waves have the highest signal to noise ratio (S/N) and it can be say the most practical tool for near surface characterization (Maheswari, Boominathan, & Dodagoudar, 2010).

In the present study, MASW tests are widely used in order to build up the shear wave velocity profile. In the MASW test, the motion produced by a mechanical impact source is identified at the same time at a few receiver areas and the relating signal are analyzed as an overall utilizing double Fourier transform. Crude field information are changed into the frequency–wave number (f–k) domain where stage velocity of Rayleigh waves are calculated to create a dispersion curve. At that point the calculated dispersion curve is inverted to appraise the Vs profile (Maheswari et al., 2010).

In this project the S-wave velocity is use to invert the data into SPT-N value. Many researcher have done some research on the relationship of SPT-N value and shear wave velocity (Badrakia, 2016). SPT-N value and S wave velocity have a strong relationship that been proof by Mr. Imai (TUMWESIGE et al.) on Figure 2.8. The other evidence have been proof by (Uma Maheswari et al., 2009) which done a test on sand and clay soil. From the test, correlation between SPT-N value and shear wave velocity is obtained on Figure 2.9 and Figure 2.10.

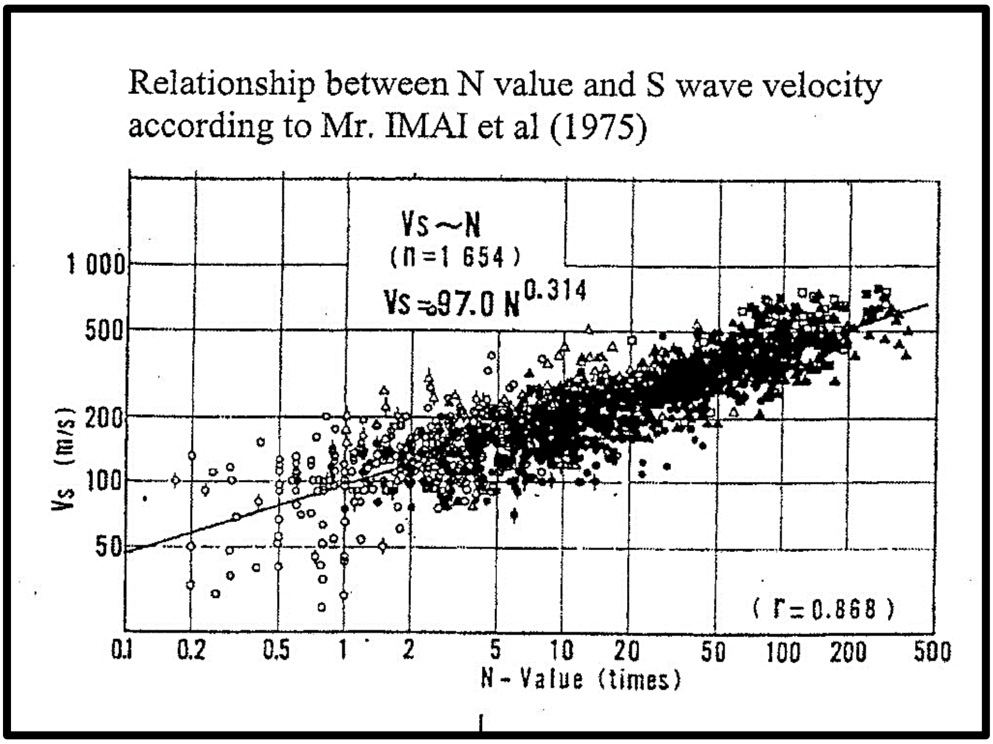


Figure 2.8 : Correlation between Vs and SPT-N value according to Mr. IMAI (TUMWESIGE, GIDUDU, BAGAMPADDE, & RYAN)

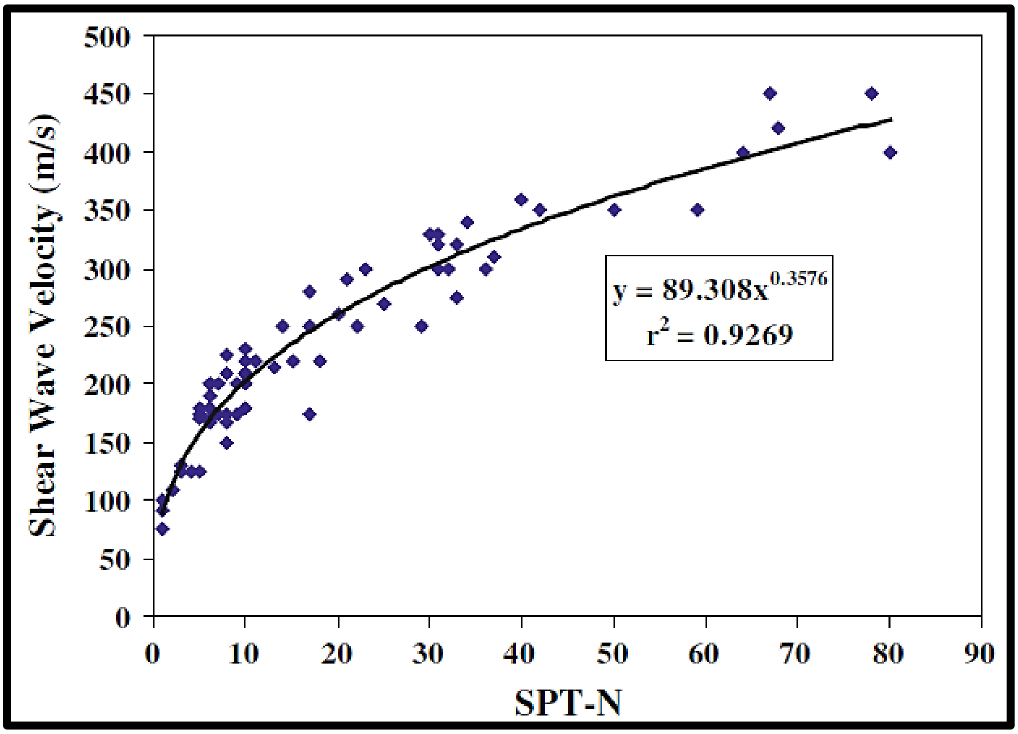


Figure 2.9 : Correlation between Vs and SPT-N value for clay (Uma Maheswari, Boominathan, & Dodagoudar, 2009)

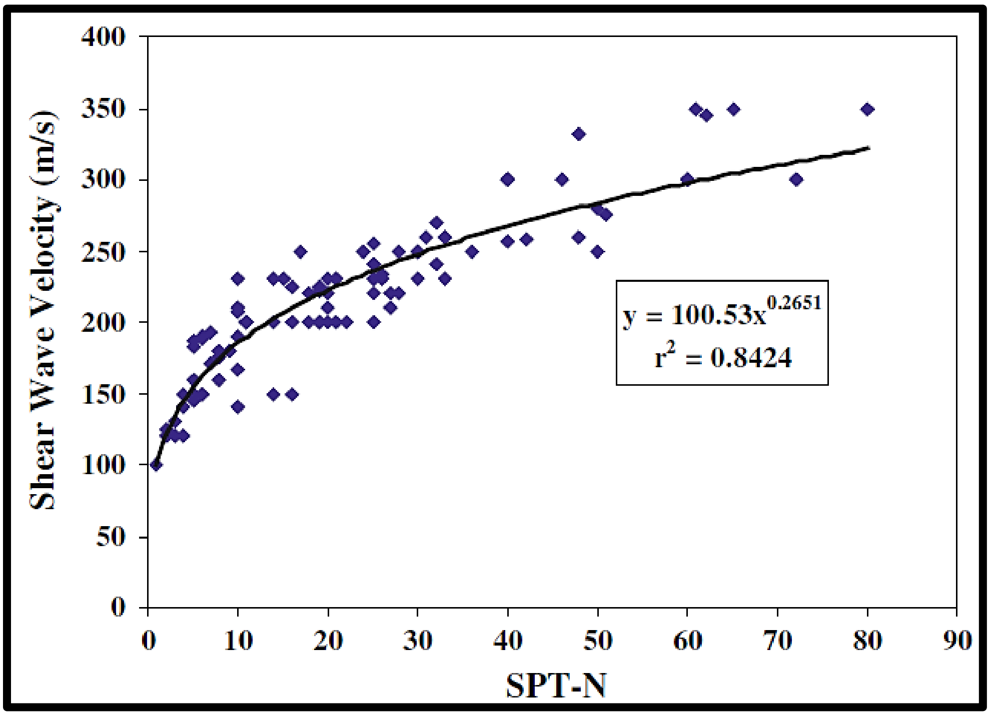


Figure 2.10: Correlation between Vs and SPT-N value for sand (Uma Maheswari et al., 2009)

2.3.1 Surface Wave Method

Mechanical blow or explosive energy with an overwhelming hammer which produce vibration that penetrate through the ground or at the shallow depth inside an opening are utilized as a part of request to obtain the underground images through the distinctive layer of subsoil that identified with spread of wave velocity is the method uses in seismic wave method. Geophones that spot on the ground surface records the propagation of elastic wave front. The dissemination of wave velocity depend on the level of compaction with a specific end goal to acquire the lithologic contacts of the geotechnical materials. The vibration of that produce from the mechanical blow create a few sorts of waves which is as shown below:

i. Primary (p) wave /longitudinal wave /compressive wave,
ii. Secondary (s) wave /transverse wave /shear waves,
iii. Surface waves

In order to investigate and gain information of the subsoil surface, there are few application of the seismic wave method which are area of the water table, depth and the characteristic of the hard rock surface, picture of the sub soil material, and so on. There are sure effect that can be get by utilizing this method, for example, up to 10m depth of ground strata can be catch, data on the properties of material at the subsoil surface can be execute from the wave's velocity and it gave high vertical resolution. The velocities of seismic that get from the test can conveyed the data on lithology, layers, and compaction of the soil.

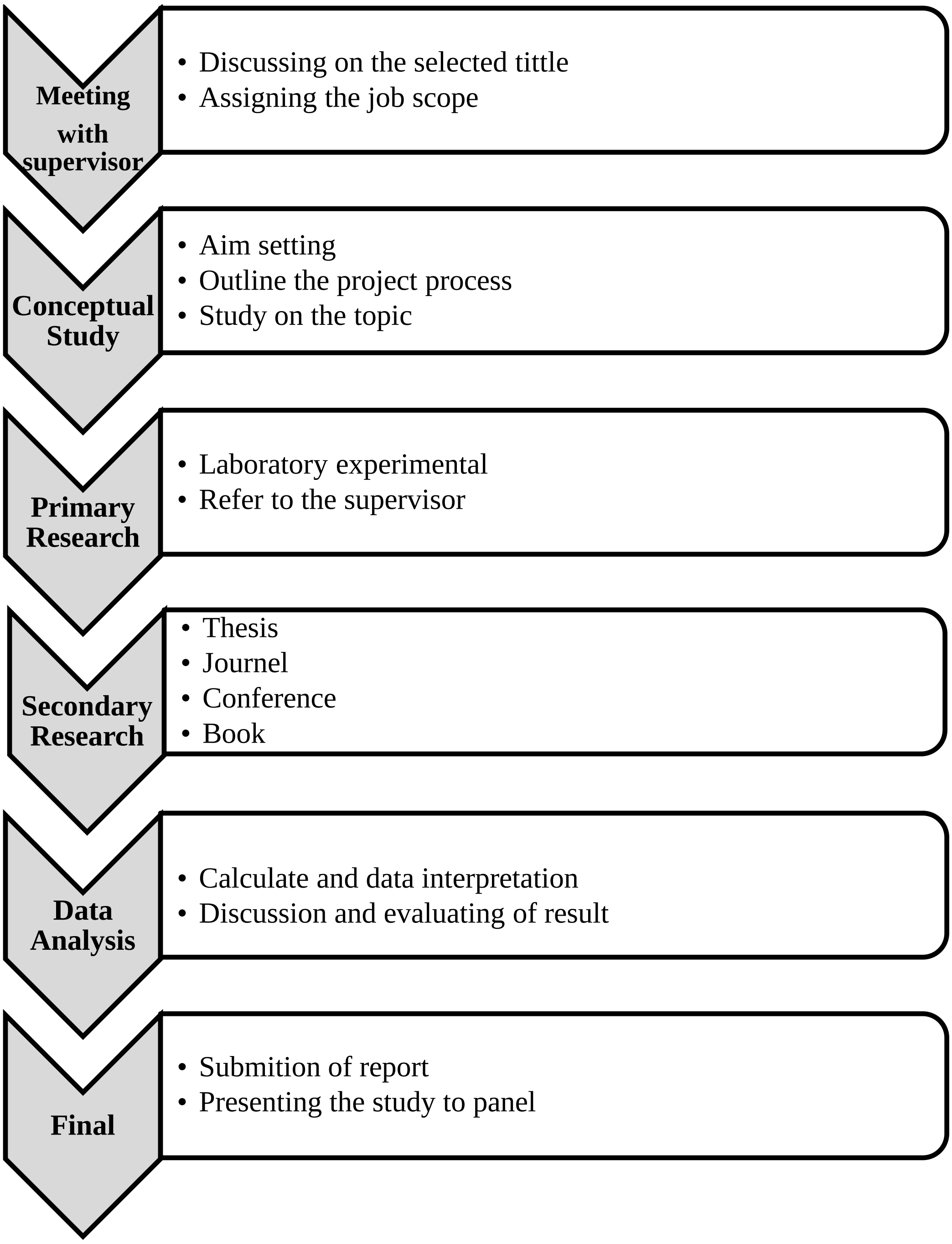
Dispersion of Rayleigh wave is one of the technique that have been utilized in order for shear wave (s-wave) estimation velocity of soil (Mohamed, Abu El Ata, Abdel Azim, & Taha, 2013). There are likewise a few other technique that empower to acquire the data of shear wave, for example, cross hole and up-hole survey. Each of the frequency components of the Rayleigh wave, they travel at difference velocity for each of it and it is known as dispersion of wave. Rayleigh wave has high signal to noise ratio (S/N) (Mohamed et al., 2013).The velocity of the wave is relies on upon the travelling of the S wave at distinction medium of soil while the depth of soil is relying upon the wavelength of the wave.

To extract the velocity along the subsoil of the ground, Multichannel analysis of surface wave (MASW) is the best technique to be implement. MASW can completely consider of the seismic waves that contain diverting noise (Penumadu & Park, 2005). By utilizing this method it give the most consistence and accurate on calculating the velocity of near surface shear waves. Contrasting the MASW method and the other customary borehole methods, there was no any complexity in the outcomes. This method has been thought to be an overwhelming method that dependably gave tried and true S-wave velocity profiles of the subsoil layer underneath the earth surface.

CHAPTER 3

METHODOLOGY

3.1 Workflow Overview



3.2 Research Overview

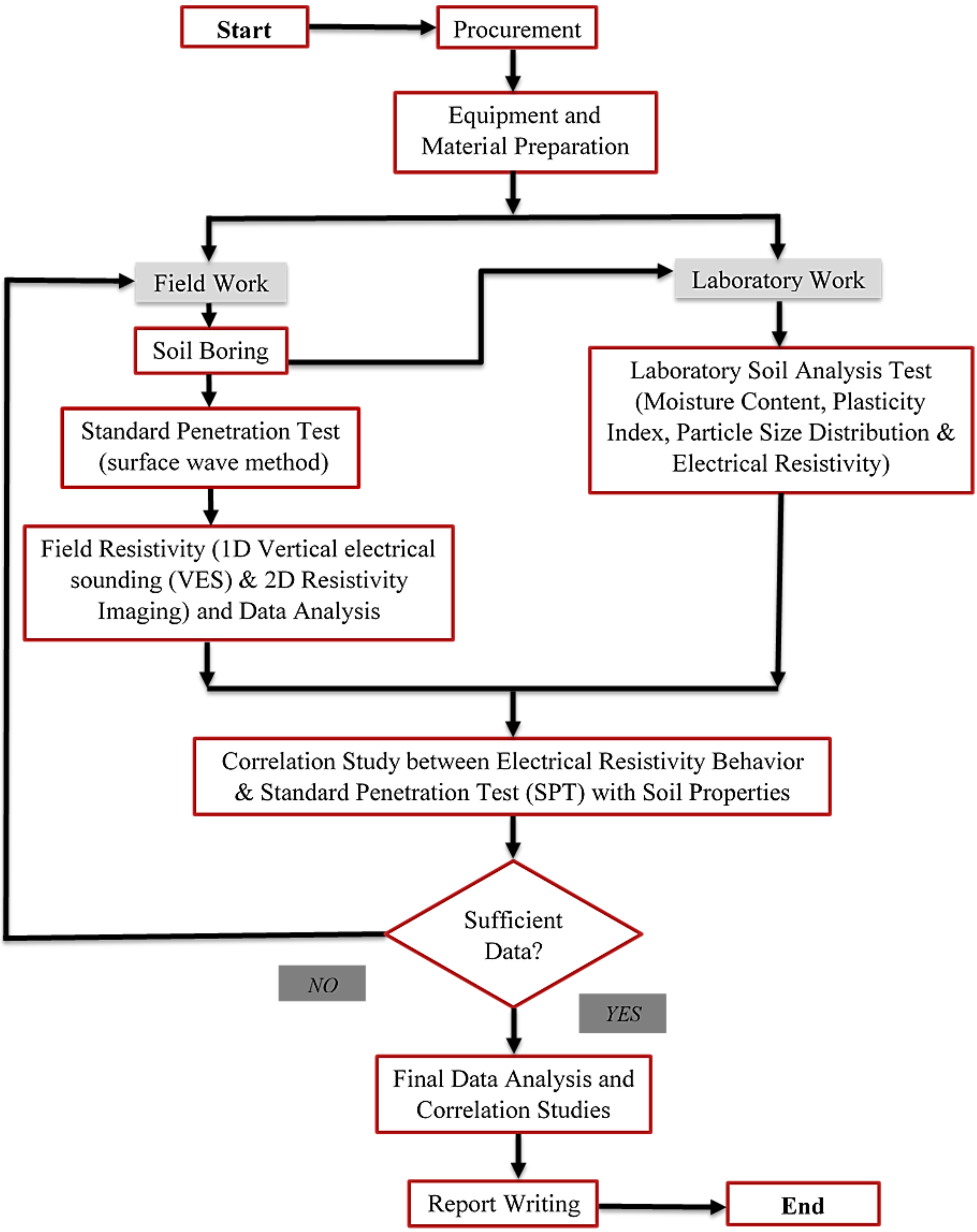


Figure 3.1: Project Flowchart

3.3 Field Investigation

3.3.1 Standard Penetration Test (SPT)

Standard Penetration Test to be carried out at 1.5m intervals. A split spoon sampler of 50 mm diameter to be driven into the soil by using a 65 kg hammer falling freely from 760 mm height. The number of blows required to obtain the initial 150mm shall be recorded for reference. Subsequent penetration of 300mm thereafter shall be recorded as the blow count of the soil strata encountered as indicative of the relative density of non-cohesive soils.

3.3.2 Electrical Resistivity Method

Wenner array

The equipment were ready at the study location for field electrical resistivity survey. Wenner array configuration was applied in order to perform this method. The electrodes were equal distance injected to the soil surface along a straight line. The spacing between the electrodes were taken as 2, 4,8,10, and 12 meters to each other. The two potential electrodes P1 and P2 are placed in the between of array while current electrodes, C1 and C2 are located at the end point of the array. As a consequence, the electrical resistivity of the subsoil surface for a particular depth were recorded. The apparent electrical resistivity of soil can be calculated by using stated formula given:

$$\rho_{\alpha} = 2\pi RL$$

ρ_{α} is the apparent electrical resistivity in ohm.m, L is the spacing between electrodes in meters and R is the measured resistance in Ohm.

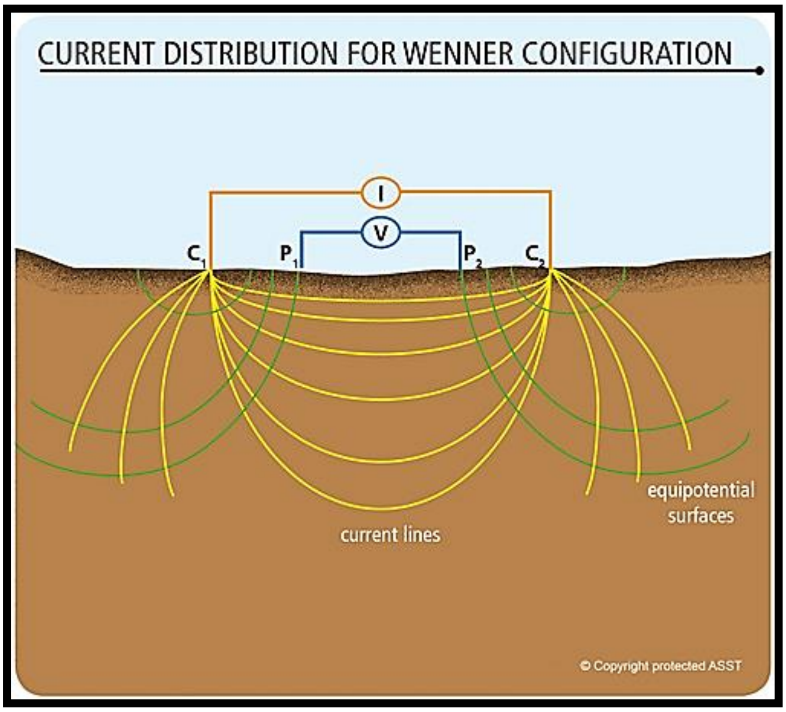


Figure 3.2: Distribution of current (Wenner Configuration)

Figure 3.3: Equipment of field electrical resistivity

3.3.3 Seismic Survey

Surface wave method

A seismic survey will be carry out by conducting Multichannel Analysis of Surface Waves (MASW) tests at 5 locations over the entire study area. The frequency of Rayleigh waves should be low to obtain the longer wavelength for increasing the depth of penetration. For that reasons, optimal seismic refraction survey has been carried out in order to record the penetration depth and frequency range. Rayleigh wave and p-wave were collected at the study area. The total number of geophones that being used is 24 with a varied spacing depends on the site area for each profile. Illustration on the seismic wave acquisition are shown in Figure 3.4.

Sledge hammer with a weight of 8 kg are used to slam on the steel plate with dimension of 20cm x 20cm x 5cm. There are total of three shot along the seismic line with 10 to 15 slam were carried out for each location of shot. The first and the second of the shot point were 25m offset from the two ends of the geophone array while the third shot point was located at the middle of the array. P wave and s wave were generate from the source point due to the slam of the steel plate by the sledge hammer as shows in Figure 3.4 (a) 24 channel of ABEM Terraloc MK8 seismograph recording system and 4.5 Hz of vertical-component geophones is been used in order to obtain the data on surface waves (Rayleigh waves), incident waves, reflected waves, and refracted waves.

The duration of each shot was set to 1024ms with a sampling interval of 0.5ms and the number of samples per trace was 2048ms. To improve the signal to noise ratio (S/N), pre-processing of the data has been carried out due to the ambient noises that generated from wind noises, traffic noises ,daily human activities and etc. The detector are place along the straight line with difference in the distance from the source of wave. The velocity of the wave will increase as the wave travel deeper of the subsoil surface.

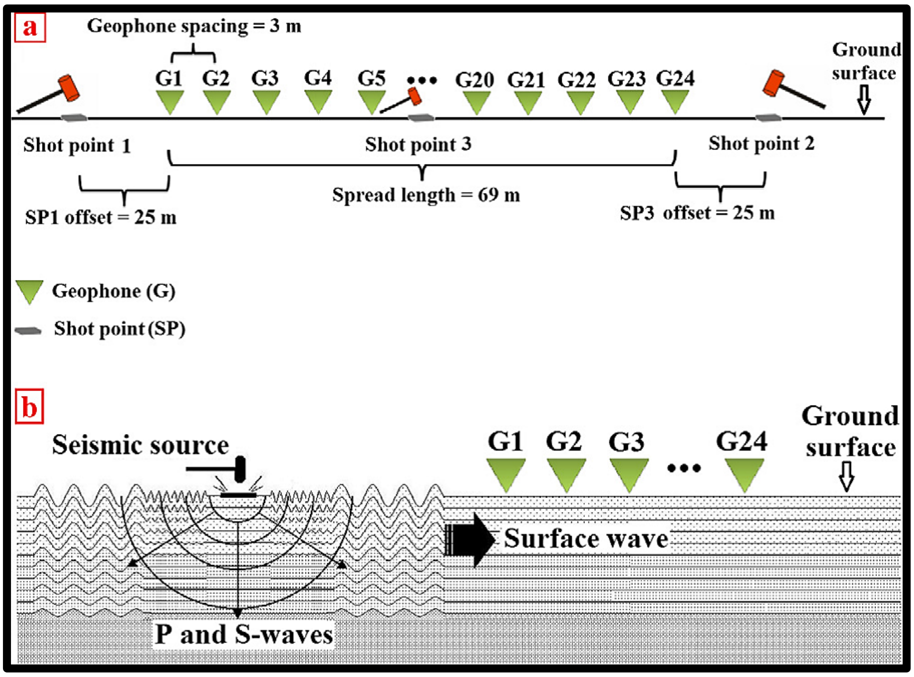


Figure 3.4: (a) location of shot point (b) propagation of wave

Figure 3.5: Equipment of seismic survey

3.3.4 Soil Boring

The soil drilling was performed by utilizing petrol-worked percussion boring set (model: CobraTT, Atlas Copco) outfitted with 1 meter center sampler to collect subsurface soil tests. The bore holes were drilled to a specific depth for undisturbed samples. The undisturbed samples were well kept in cylindrical plastic and topped firmly and numbered by depths and boreholes.

Figure 3.6: Process of soil boring and sampling

3.4 Laboratory Test

a) Atterberg Limit Test (Plasticity Index)

i. Liquid Limit (Cone Penetrometer Method)

Moisture content at which it is expressed as a percentage of dried soil weight and it is about at the boundary of liquid and plastic states. 150 g of air dried soil sample passing 0.425 mm (No. 40) sieve were mix with distilled water to form a uniform paste by using spatula on a flat glass plate (500x500x10mm). The wet soil then been transfer to cylindrical cup and ensure no air trapped in this process with level up to the top of cup. The penetrometer is adjusted until the cone point just touches the soil paste. The vertical clamp is release to allow the cone point to penetrate the soil paste for 5 seconds and record the reading. Repeat the test for at least four time and dried the sample in the oven for 24 hours to determine the moisture content of the sample.

ii. Plastic Limit (Hand Rolling Method)

Moisture content of a soil at which it is expressed as a percentage of dried soil weight and it is about at the boundary between plastic and semisolid. The moisture content of the soil at which the soil are about to crumble when rolled into a thread to about 3mm of diameter. 20 g sample passing 0.425 mm (No. 40) sieve were mix with distilled water and form the mixture into a ball shape. The ball shape sample are then cut into four equal quadrant by using spatula on a flat glass plate (500x500x10mm). One of four quadrant of the sample are taken to be roll between the palms with sufficient pressure. The sample must be rolled into 3mm in diameter and until the thread form a crumbles. Repeat the process for the other quadrant of the sample and dry the sample in the oven for 24 hours to determine the moisture content of the sample.

$$Plastic\ Index\ (PI) = Liquid\ Limit\ (LL) - \ Plastic\ Limit\ (PL)$$

b) Moisture Content

The small portion of the wet soil has been taken to be oven-dry for 24 hours. The initial mass of the soil (wet soil) and the final mass of the soil (dry soil) has been recorded in order to calculate the moisture content of that particular soil.

$$Moisture\ Content\ (\%) = \left(\frac{wet\ weight\ (g) - dry\ weight\ (g)}{dry\ weight\ (g)}\right) \times 100$$

c) Particle Size Distribution

The process of sieve analysis involve of shaking the soil sample through a set of sieves that have progressively smaller opening. U.S. standard sieve number and the sizes of opening are given in Figure 3.7. In order to conduct the sieve analysis, first the soil must be oven-dry and break the soil into a small particle and shake the soil by using shaker through the stack of different size of sieve opening from big to small. After the soil has been shacked, the mass of retaining soil on each sieve is recorded.

Standard US-sieve size

US-Sieve Size (mesh)	Opening (mm)	US-Sieve Size (mesh)	Opening (mm)
2.5	8.00	35	0.500
3	6.73	40	0.420
3.5	5.66	45	0.354
4	4.76	50	0.297
5	4.00	60	0.250
6	3.36	70	0.210
7	2.83	80	0.177
8	2.38	100	0.149
10	2.00	120	0.125
12	1.68	140	0.105
14	1.41	170	0.088
16	1.19	200	0.074
18	1.00	230	0.063
20	0.841	270	0.053
25	0.707	325	0.044
30	0.595	400	0.037

Source: Perry, R. H., Chilton, C. H., and Kirkpatrick, S. D. 1963. *Chemical Engineers Handbook*, 4th ed. McGraw-Hill Book Co., New York.

Figure 3.7: Standard US sieve size

d) Laboratory Electrical Resistivity

At that point, soil tests from different depths were analyzed for its resistivity value in laboratory condition. This method is known as disk electrode (BS 1377: Part 3: 1990: 10.2) where two electrodes plate will mounted on every side of soil samples. The disks will be clasped to ensure the disk and soil oppose before the electrical potential (30, 60 and 90 volts) connected. The soil resistivity can be ascertained based equations below.

$$R = \frac{V}{I}$$

$$r_s = \left(\frac{A}{L}\right)R$$

Where:

R is resistance calculated from applying volts divide captured current from soil

A is the cross sectional area

L is the length of the sample

r_s is the resistivity value

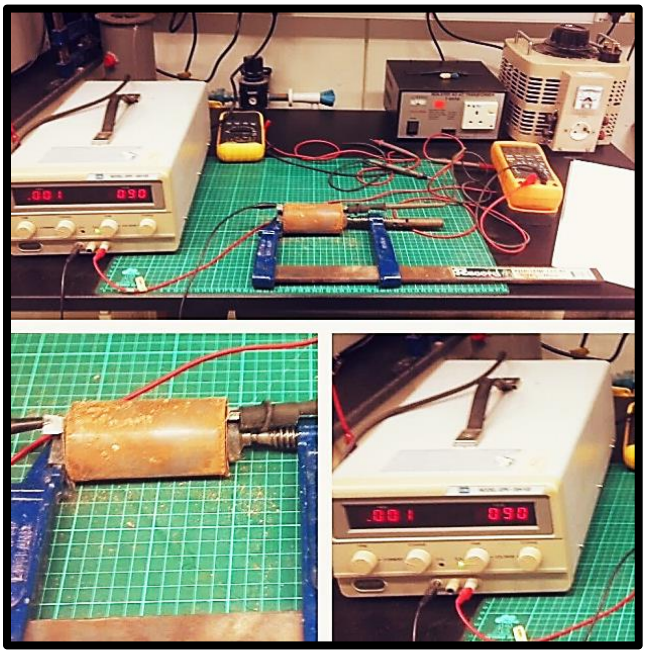


Figure 3.8: Equipment and process of laboratory electrical resistivity

3.5 Project Milestone

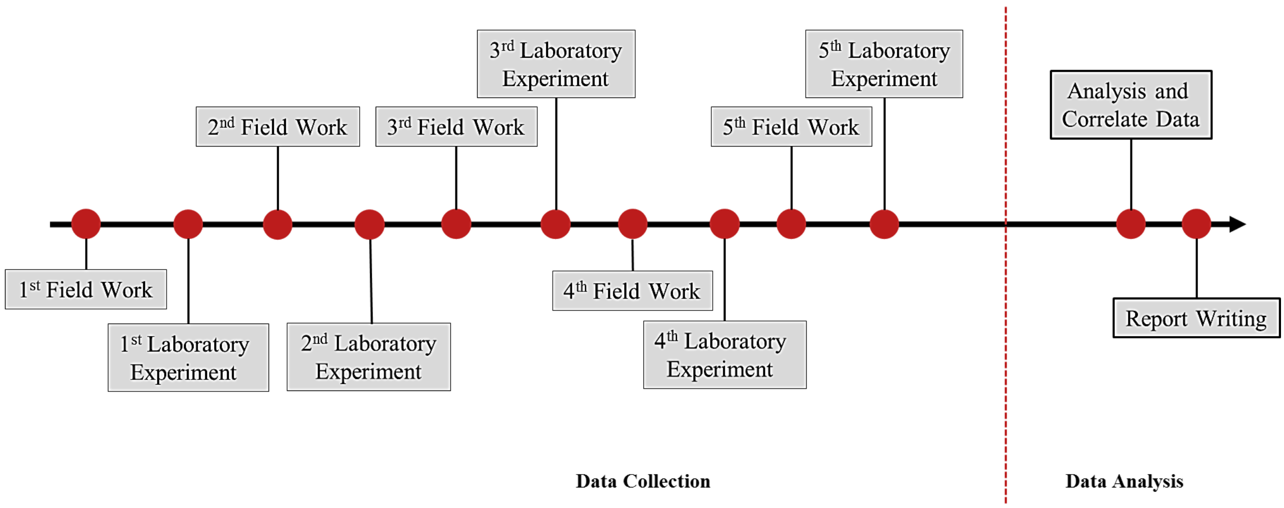
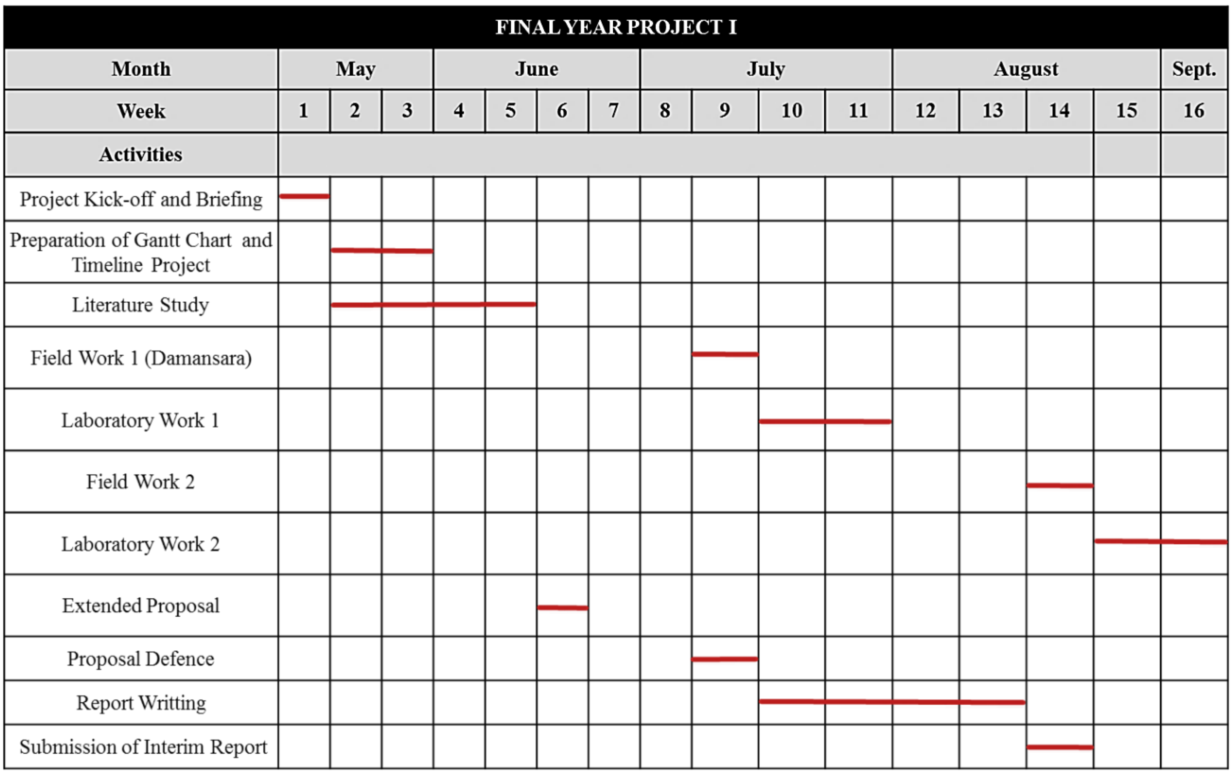


Figure 3.9: Key Milestone

3.6 Gantt Chart



FINAL YEAR PROJECT I																
Month	**May**			**June**				**July**				**August**				**Sept.**
Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Activities																
Project Kick-off and Briefing																
Preparation of Gantt Chart and Timeline Project																
Literature Study																
Field Work 1 (Damansara)																
Laboratory Work 1																
Field Work 2																
Laboratory Work 2																
Extended Proposal																
Proposal Defence																
Report Writting																
Submission of Interim Report																

Figure 3.10: Proposed Gantt chart for FYP I

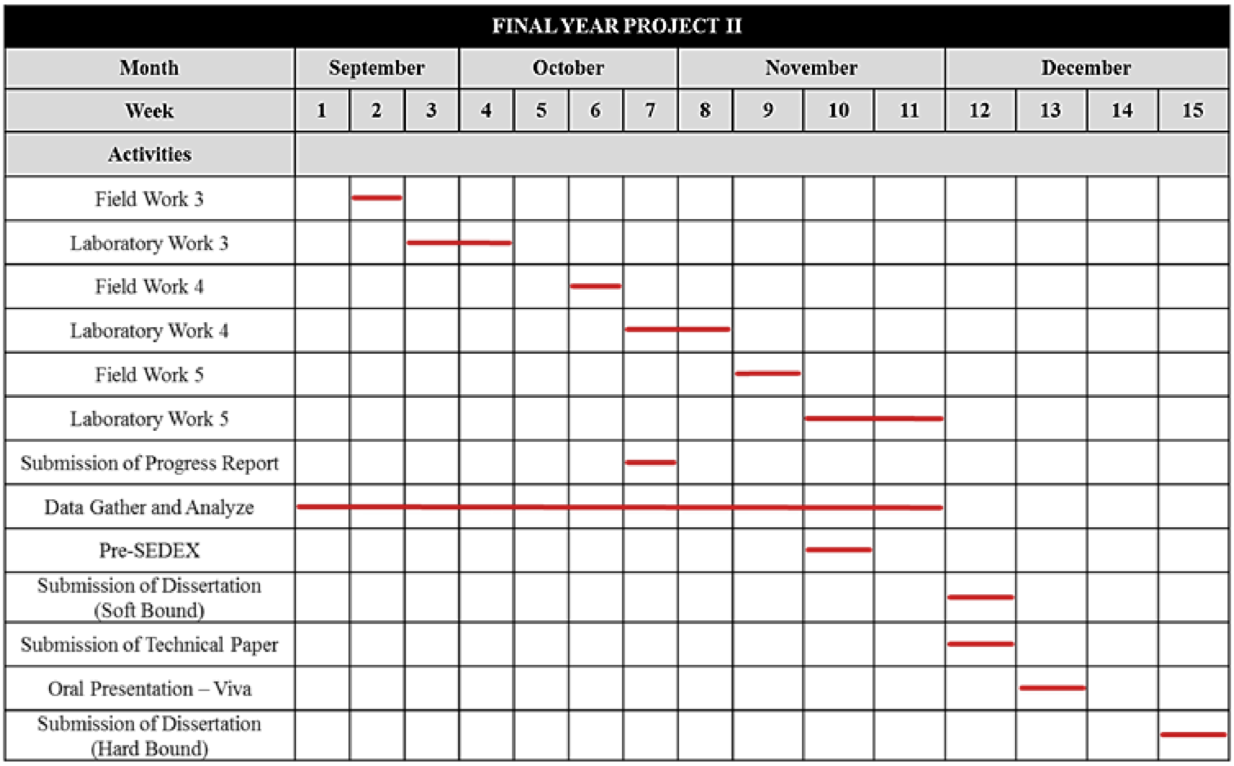


Figure 3.11: Proposed Gantt chart for FYP II

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Field and Laboratory Results

Results from field and laboratory test have been taken from area of Damansara, Melaka, Perlis, Cameron Highland and Pekan which consists of 10 boreholes with 2 boreholes every site. The properties of soils were investigated according to depth of boreholes in ranges from 1.0m to 3.0m with 1.0m depth interval. The field work that been carried out in UTP is just for the purposed of verification of SPT-N (Seismic) with SPT-N (Borehole). The sample from all the sites were brought to laboratory for soil classification test such as moisture content, plasticity index, particle size distribution and laboratory electrical resistivity. The N-value converted from seismic method, 2D apparent electrical resistivity 2D inverted electrical resistivity and particle size distribution results are attached at the appendices. From the results obtained in five of the studied area (Damansara, Melaka, Perlis, Cameron Highland and Pekan), it can be concluded that the soil from all borehole falls within the range of following descriptions:

i. Moisture content ranged between 15.38% - 116.17%
ii. Plasticity index (PI) ranged between 8.74% - 38.63%
iii. SPT-N value ranged between 1 – 16
iv. Inverted resistivity ranged between 8.02 Ohm.m – 1726 Ohm.m

Location	Borehole	Depth (m)	SPT-N value (Seismic)	Moisture Content (%)	P.Index	Lab. Resistivity (ρa)	Inverted Resistivity (ρa)
DAMANSARA - 1	BH 1	1.0	15	16.48	19.11	1593.44	1726.00
		2.0	15	15.38	22.62	707.13	1500.00
		3.0	15	16.48	21.06	1134.28	150.00
DAMANSARA - 2	BH 2	1.0	11	18.95	22.86	14458.79	1088.00
		2.0	12	16.46	22.60	7876.51	650.00
		3.0	16	21.4	20.50	3670.76	170.00
MELAKA - 1	BH 3	1.0	3	74.11	19.45	15.18	118.90
		2.0	4	90.68	30.67	4.40	145.80
		3.0	4	100.43	38.63	2.02	157.80
MELAKA - 2	BH 4	1.0	3	24.31	17.86	15.94	24.76
		2.0	4	71.61	23.55	4.61	24.63
		3.0	4	91.72	22.52	1.86	19.63
PERLIS - 1	BH 5	1.0	4	71.52	22.32	0.89	9.66
		2.0	3	116.17	26.28	0.45	17.53
		3.0	3	86.30	20.72	0.44	24.39
PERLIS - 2	BH 6	1.0	4	69.99	22.53	0.81	10.02
		2.0	3	91.86	14.00	1.23	19.40
		3.0	3	95.65	18.30	2.27	28.36
CAMERON - 1	BH 7	1.0	3	24.88	11.50	383.57	198.60
		2.0	5	22.45	10.01	738.17	213.20
		3.0	5	23.24	9.84	994.62	213.40
CAMERON - 2	BH 8	1.0	3	20.92	14.77	636.01	193.00
		2.0	5	24.84	15.52	623.03	212.30
		3.0	6	26.69	13.52	717.29	188.90
PEKAN - 1	BH 9	1.0	2	57.34	25.80	24.24	8.02
		2.0	1	93.90	18.10	31.90	15.63
		3.0	2	52.22	8.74	39.59	23.22
PEKAN - 2	BH 10	1.0	2	69.97	20.53	36.65	20.69
		2.0	1	69.10	23.47	20.37	40.28
		3.0	2	46.77	9.88	35.07	59.80
UTP (Line1) **verification purposed**	(BH1)	1.5	24	13.00	12.00	N/A	350.00
		3.0	22	5.00	4.00	N/A	280.00
		4.5	20	10.00	6.00	N/A	160.00
		6.0	24	32.00	20.00	N/A	663.40
	(BH2)	1.5	26	13.00	5.00	N/A	492.00
		3.0	20	13.00	12.00	N/A	263.00
	(BH3)	1.5	18	41.00	22.00	N/A	270.00
		3.0	22	35.00	21.00	N/A	80.00
		4.5	14	37.00	17.00	N/A	69.00
UTP (Line2) **verification purposed**	(BH4)	1.5	5	34.00	22.00	N/A	220.00
		3.0	3	34.00	17.00	N/A	150.00
		4.5	9	31.00	27.00	N/A	75.00
		6.0	10	36.00	20.00	N/A	50.00
		7.5	10	25.00	14.00	N/A	45.00
		9.0	17	19.00	10.00	N/A	36.00
		10.5	15	14.00	5.00	N/A	34.00
	(BH6)	1.5	6	27.00	11.00	N/A	143.00
		3.0	6	29.00	15.00	N/A	25.70
		4.5	14	18.00	12.00	N/A	28.00
		7.5	18	16.00	8.00	N/A	39.50
		9.0	19	18.00	14.00	N/A	59.80
		10.5	16	12.00	11.00	N/A	60.80
		12.0	18	15.00	6.00	N/A	60.00
	(BH10)	1.5	6	19.00	12.00	N/A	68.00
		3.0	6	23.00	18.00	N/A	39.50

Figure 4.1: Summary data of geotechnical and physical properties of soil samples

Figure 4.1 is the summarized of all data included SPT-N value, moisture content, plasticity index, laboratory electrical resistivity and inverted electrical resistivity. Based on the Figure 4.1, it can be seen that based on SPT-N value, the most highest value is 16 which at location of Damansara (BH2,3m) where the soil is very stiff, while the lowest SPT-N value is 1 for location at Pekan (BH9,2m ; BH10,2m) where the soil is very soft. Besides, moisture content is also an important parameter that should take into consideration in correlation with SPT-N value and inverted electrical resistivity. There are slight different in results between laboratory electrical resistivity and inverted electrical resistivity can be observed in Figure 4.1. These were probably due to some reasons which are the contact point of electrode inset into the ground may be different, some of it would be loose and not well inserted into the ground. Besides, surface area covered in field (inverted electrical resistivity) were very wide compared to laboratory electrical resistivity and method of handling the measurement in laboratory also produced some error which contribute to some differences in results between field and laboratory test of electrical resistivity.

The data obtained from the software for field electrical resistivity were in the form of apparent and inverted resistivity. The apparent resistivity is where the software interpreted the soil to be in homogeneous condition which the soil type were the same throughout the strata. From the apparent resistivity results, the software were inverse the results obtained and consider the soil to be in heterogeneous condition which the soil type were not the same throughout the strata. The interpretation of electrical resistivity were made from inverted resistivity results to obtain the information of the subsurface soil.

Location	Borehole	Depth (m)	Actual N-value	Seismic N-value
UTP (Line 1)	BH1	1.5	18	24
		3	25	22
		4.5	32	20
		6	39	24
		7.5	50	34
	BH2	4.5	20	17
		6	13	19
		7.5	15	24
		9	43	46
		10.5	30	40
		12	50	49
UTP (Line 2)	BH4	1.5	7	5
		3	4	3
		4.5	10	9
		6	9	10
		7.5	9	10
		9	16	17
	BH6	1.5	10	6
		3	11	6
		4.5	25	14
		7.5	25	18
	BH10	1.5	6	6
		3	6	6
		4.5	31	10
		7.5	16	16
		9	18	18

Figure 4.2: Summary data of actual N-value and seismic N-value

4.2 Verification of SPT-N (Seismic) with SPT-N (Borehole)

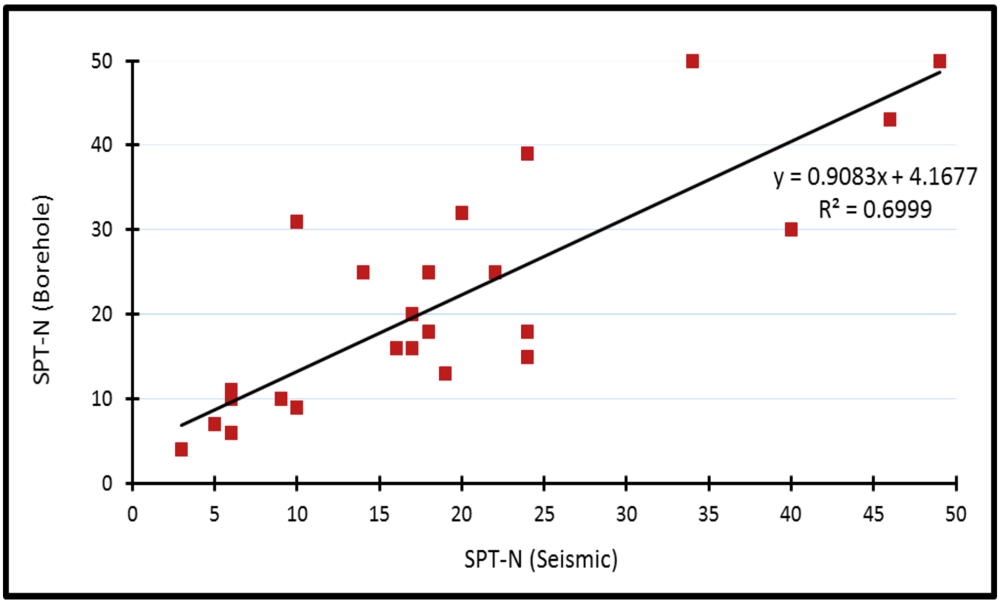


Figure 4.3: Correlation of SPT-N (Seismic) and SPT-N (Borehole)

Based on Figure 4.3, it shows a correlation of SPT-N (Seismic) and SPT-N (Borehole). The results of SPT-N (Borehole) is obtained from conventional method of standard penetration test while SPT-N (Seismic) is obtained from surface wave method. The conventional standard penetration test has been conducted at some areas in UTP. The purpose of this correlation is to shows that the results obtained from surface wave method would represent the actual N-value. From the result it shows a moderate linear correlation of SPT-N (Borehole) and SPT-N (Seismic) with regression number of ($R^2 = 0.6999$). More fieldwork for verification purposes should be done in different geological condition in order to obtain a good and precise results.

4.3 Correlation of Geotechnical Data with Electrical Resistivity

4.3.1 Inverted Electrical Resistivity versus SPT-N (Seismic)

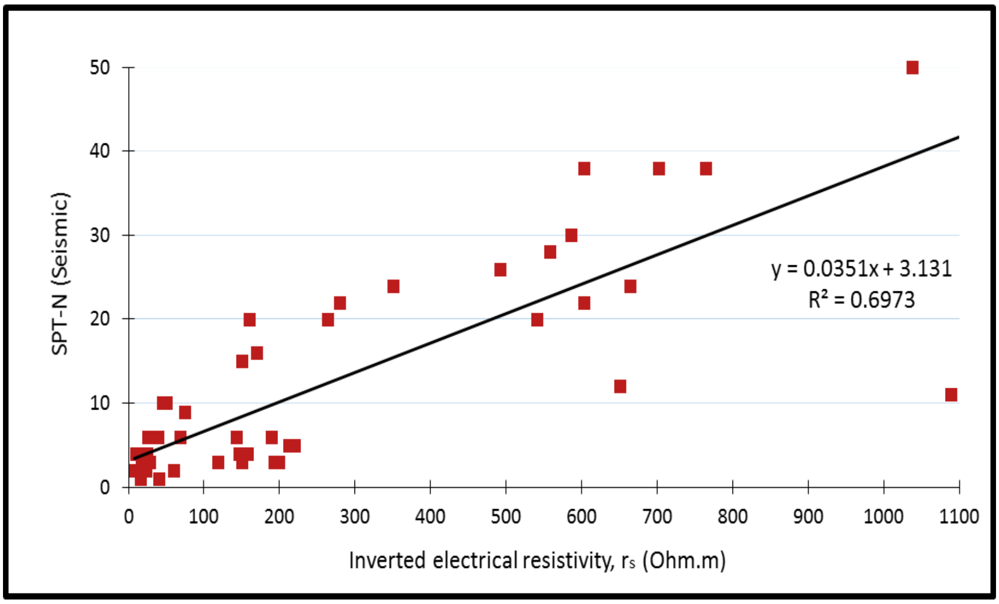


Figure 4.4: Correlation of inverted electrical resistivity and N-values

In this research the SPT-N value will be obtained by surface wave method. From the Figure 4.4, it shows a moderate linear relation between inverted electrical resistivity and SPT-N value ($R^2 = 0.6973$). The electrical resistivity increases as SPT-N value increases and vice versa. This can be explained that as the SPT-N value increase it represent that the soil has higher strength capacity. For example the soil has tight arrangement and lead to the high resistance for the current to flow through the soil matrix.

4.3.2 Inverted Electrical Resistivity versus Moisture Content

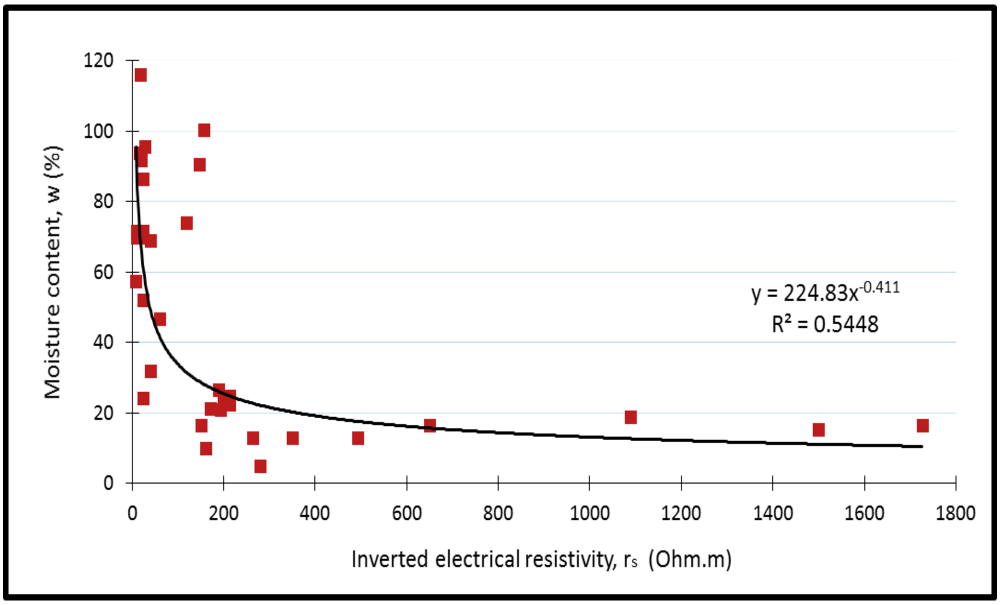


Figure 4.5: Correlation of inverted electrical resistivity and moisture content

Figure 4.5 shows a moderate non-linear relationship between inverted electrical resistivity and moisture content of the soil (R^2 = 0.5448). From the results it shows that at low moisture content, high variation in electrical resistivity value is obtained. This deviation is probably due to the different grain size distribution as the increase in grain size offers more resistance to the ionic current flows through the soil matrix. Moreover, it can be observed that higher the amount of moisture content, the lower is the electrical resistivity of a soil. This is due to the moisture has high conductivity to allow the current flows through the soil matrix and as the result the electrical resistivity will decreases.

4.3.3 SPT-N (Seismic) versus Moisture Content

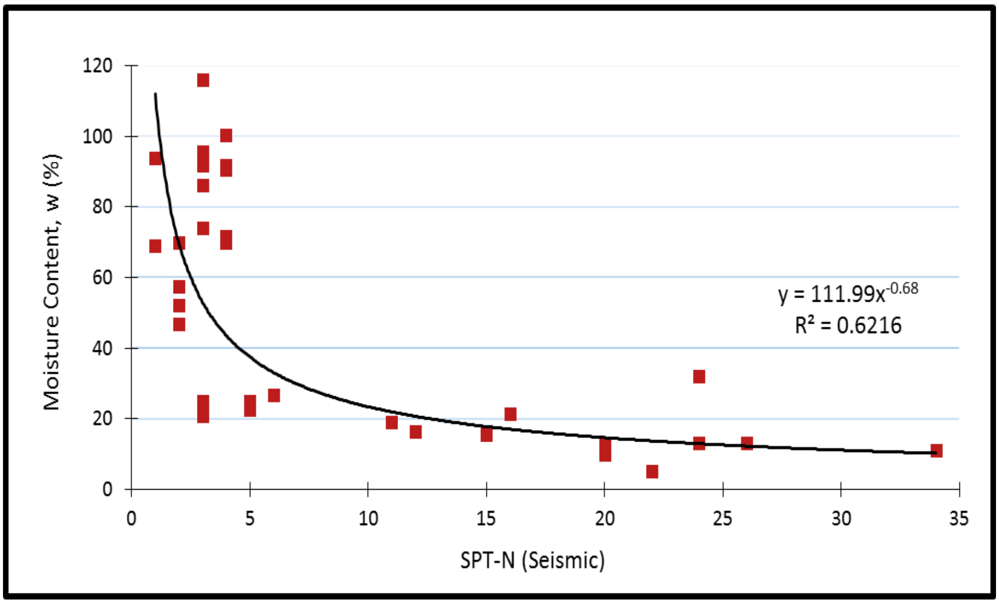


Figure 4.6: Correlation of N-values and moisture content

Moisture content of soil is the quantity of water contained in the soil and it can be express in term of percentage. Moisture content influent the behavior as well as the physical properties of the soil. From the analysis, the obtained results indicate a non-linear relation between moisture content and SPT-N value with regression number of (R^2 = 0.6216). It is evident from Figure 4.6 that N-value increases as the moisture content decreased. This is because decreases in moisture content in the soil, it causes the strength of the soil increase and as the result it required more amount of blow to penetrate the soil to a certain depth for standard penetration test.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Electrical resistivity is one of the quick and easy method in obtaining the information on the subsoil material. The results from standard penetration test (SPT), electrical resistivity and laboratory tests were analyzed together to understand the interrelation of the inverted electrical resistivity, N-value and moisture content of soil. A moderate linear relationship between inverted electrical resistivity and SPT-N value with regression number of (R^2 = 0.6973) indicates that low resistivity values usually have low N-values and vice versa. Relationship between moisture content and inverted electrical resistivity values also demonstrate a satisfactory correlation with regression number of (R^2 = 0.5448). Within the limitation of this research work, it can be presumed that correlations were established and obtained results showing the possibility to utilize electrical resistivity survey as an alternative to standard penetration test SPT. More field tests needs to be conducted in different geological conditions in order to establish more precise and general correlation between SPT N-values and electrical resistivity of soil.

5.2 Recommendations

The following recommendations are proposed for study:

i. The obtained correlations of resistivity and SPT-N values are specific to a certain types of soil. More tests and field surveys should conducted in different geological conditions.

ii. More data is needed to correlate the resistivity values with actual SPT and more seismic work is required to verified the correlation between actual SPT and converted SPT calculated from seismic surface wave software.

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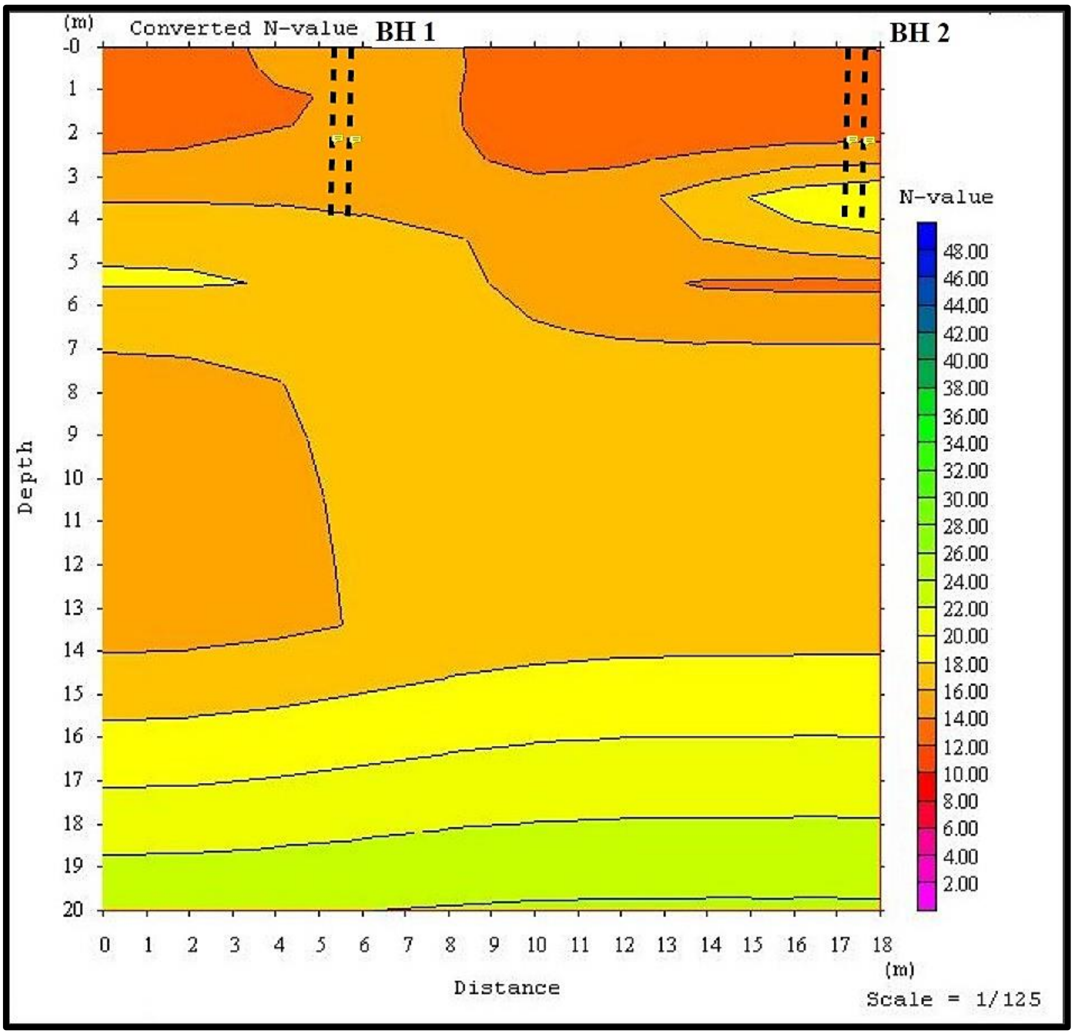
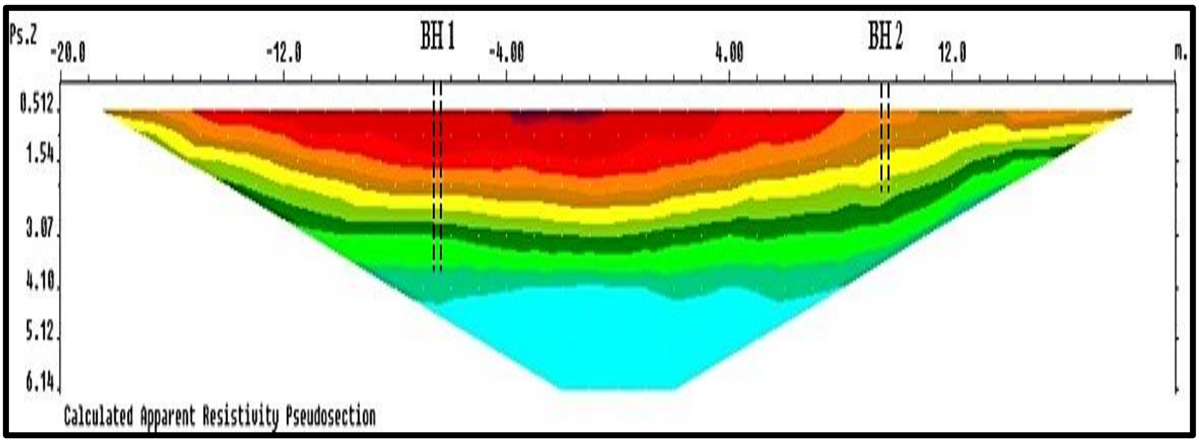
APPENDICES

Location: Damansara

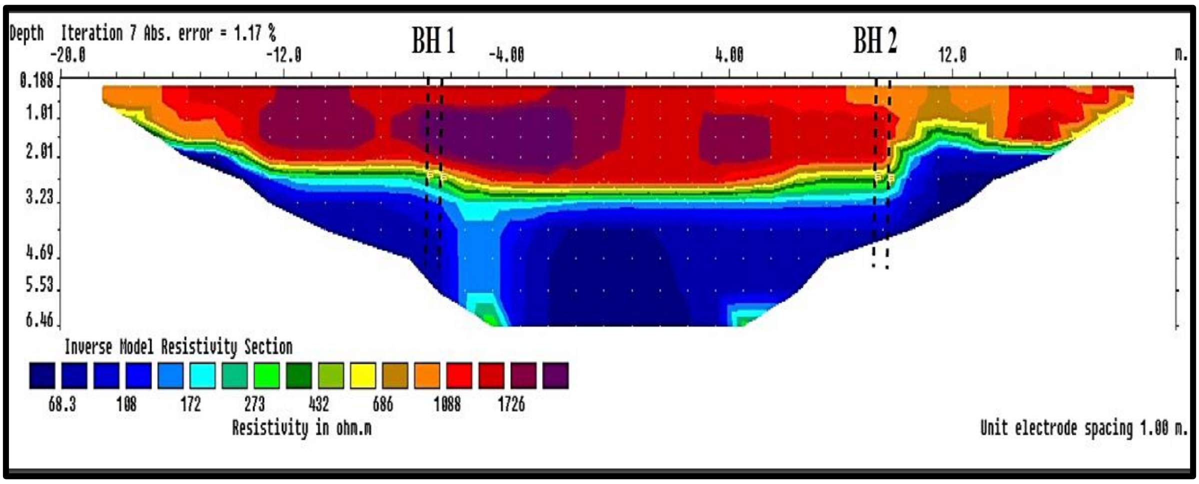
Seismic Converted to N-Value



2D Apparent Electrical Resistivity

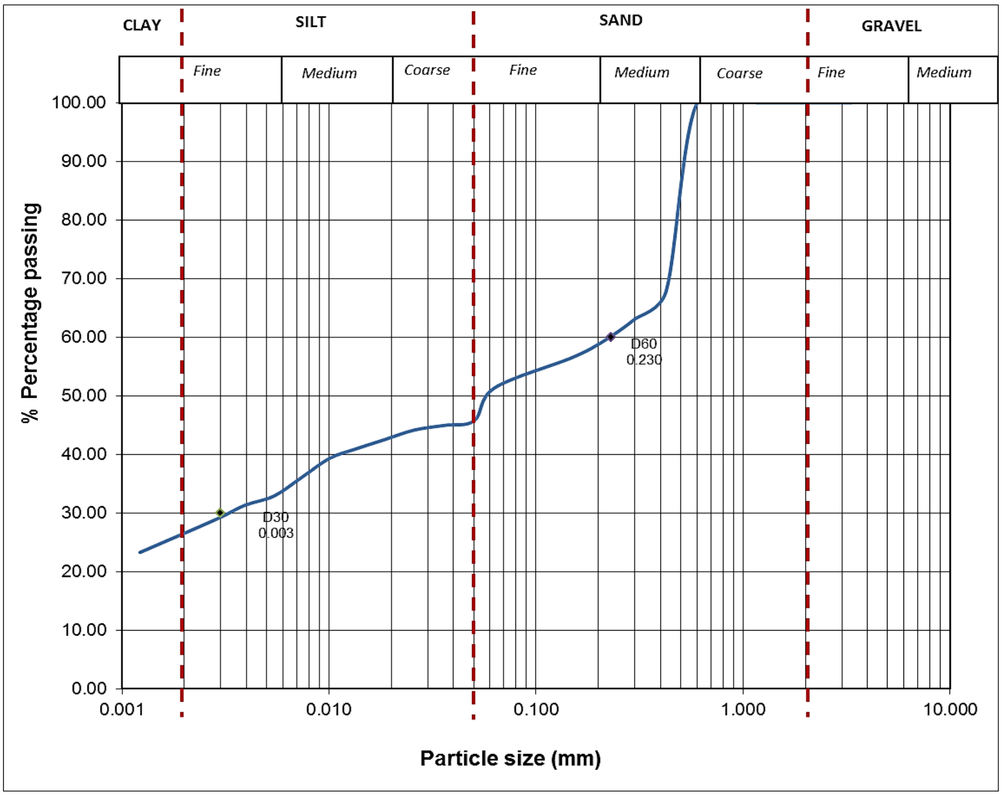


2D Inverted Electrical Resistivity

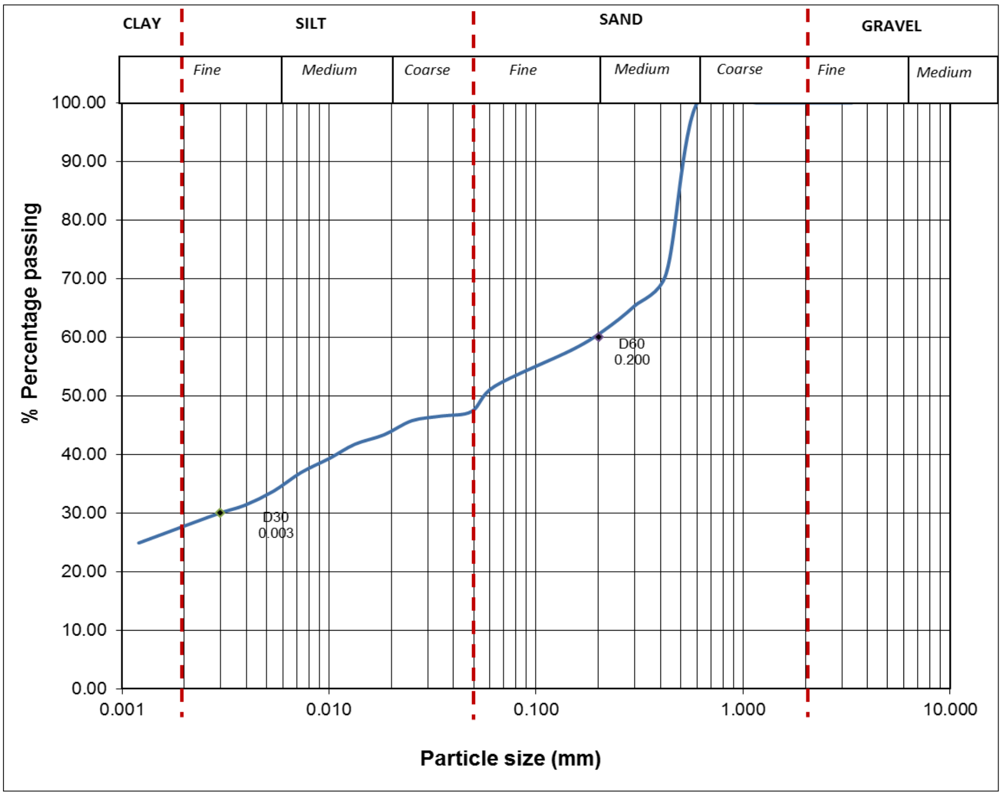


Particle Size Distribution

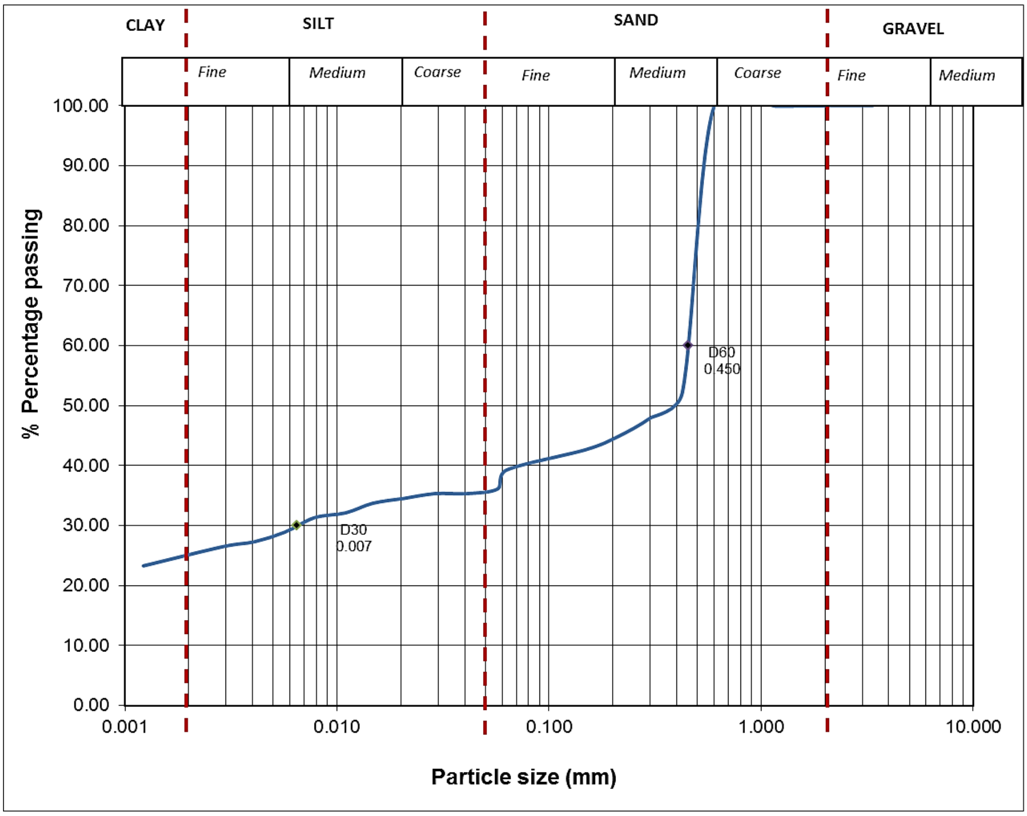
BH1-(1m)



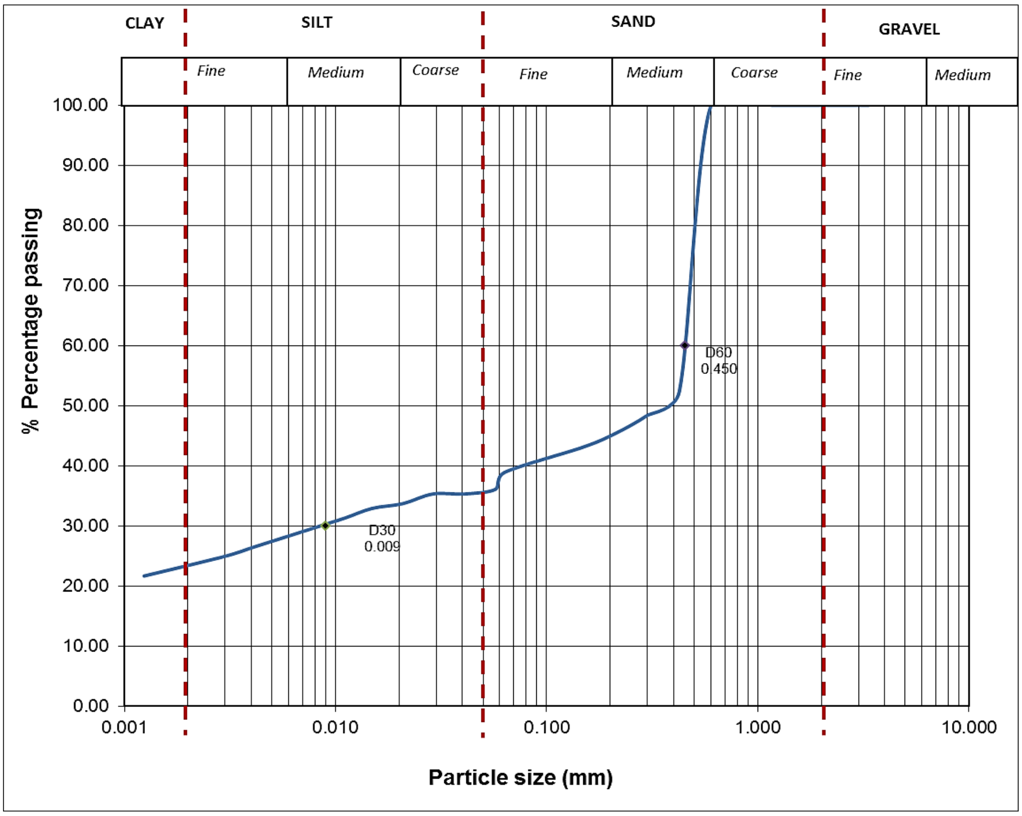
BH1-(2m)



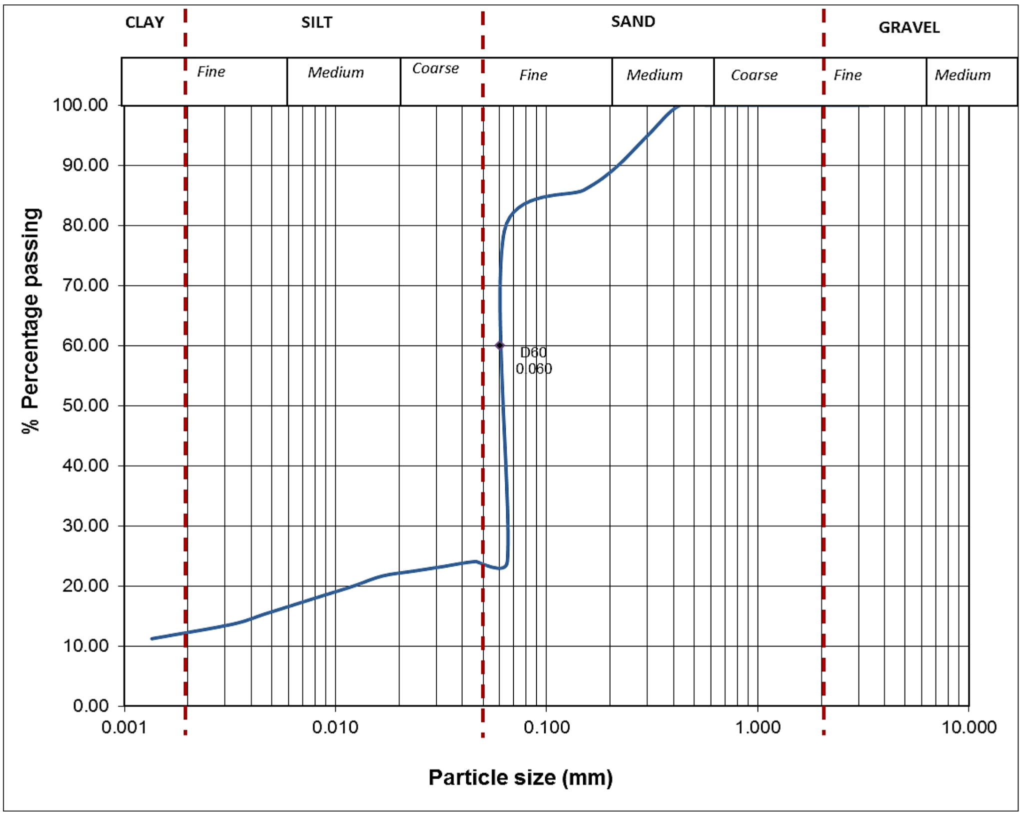
BH1-(3m)


CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Percentage passing
D60
0.450
D30
0.007
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

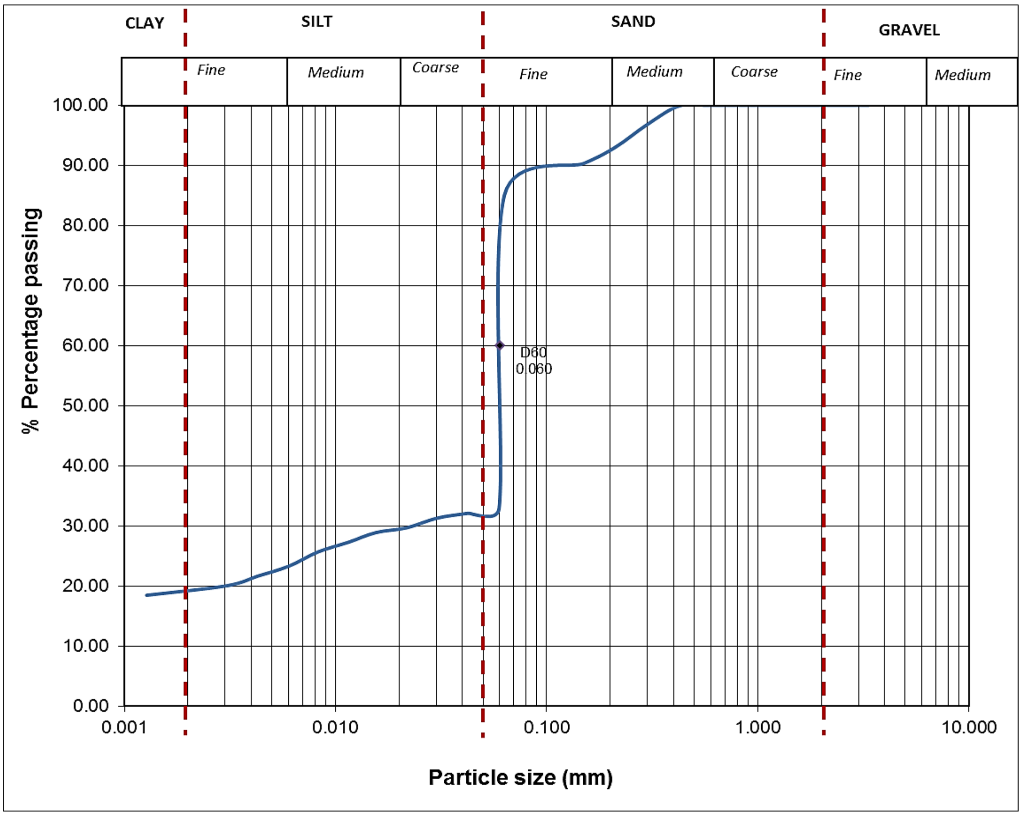
BH2-(1m)


CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Percentage passing
D60
0.450
D30
0.009
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

BH2-(2m)

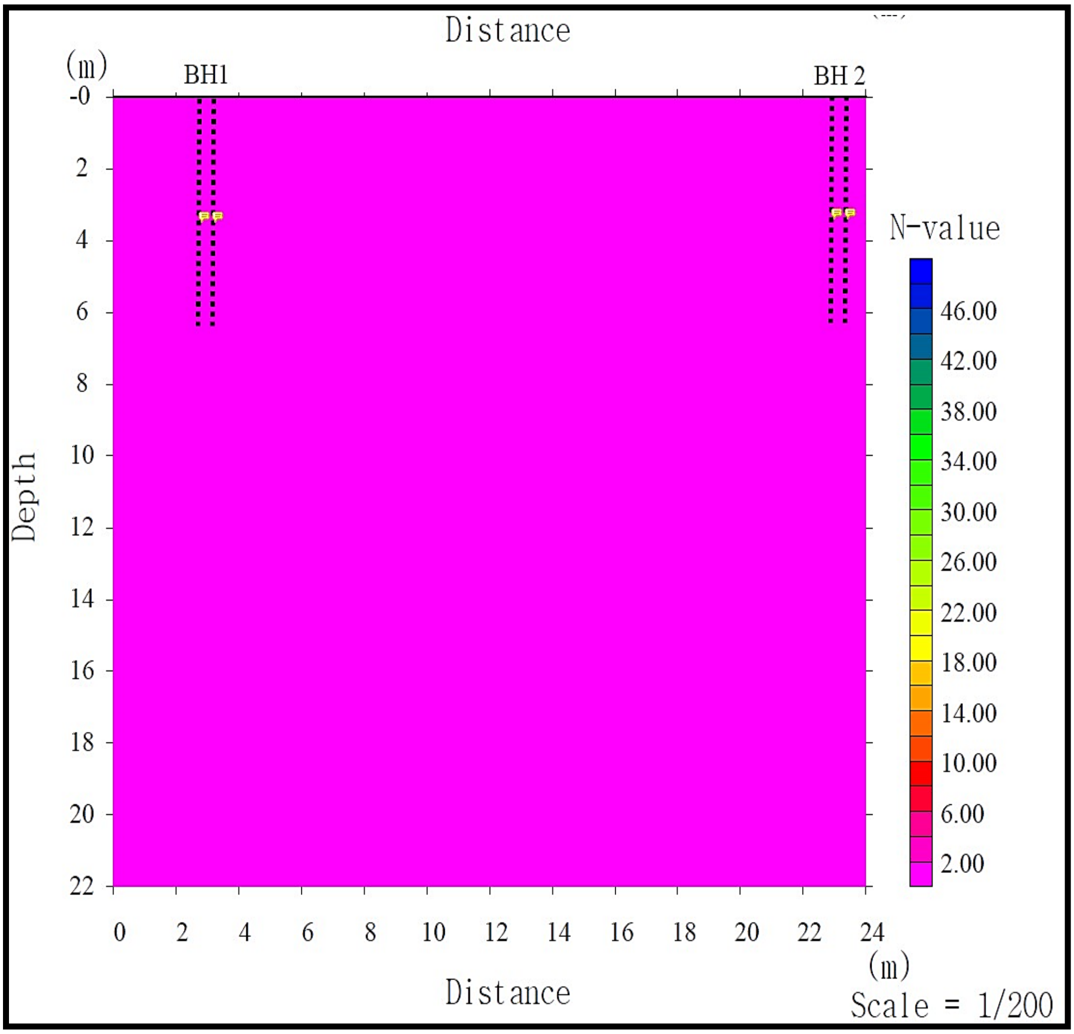

CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
% Percentage passing
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.001
0.010
0.100
1.000
10.000
D60
0.060
Particle size (mm)

BH2-(3m)

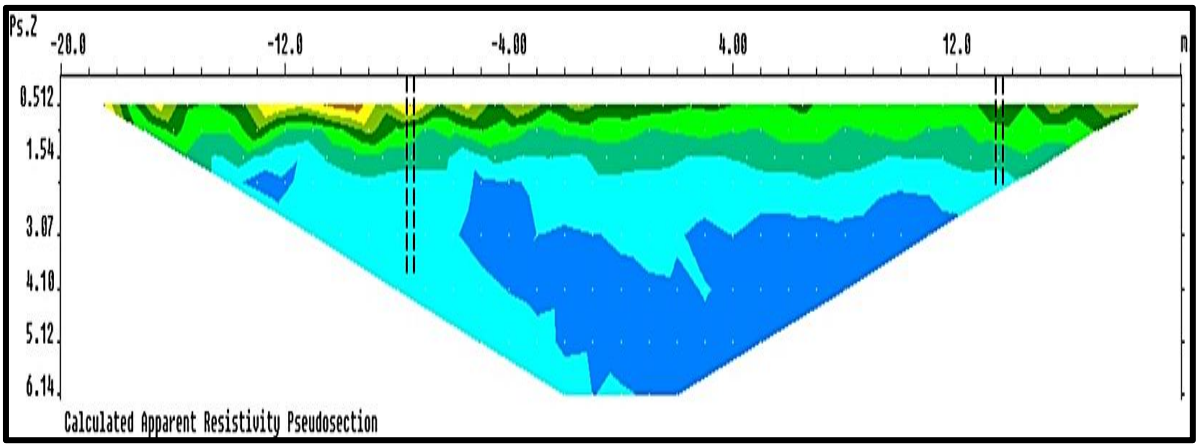

CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
% Percentage passing
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.001
0.010
0.100
1.000
10.000
D60
0.060
Particle size (mm)

Location: Melaka

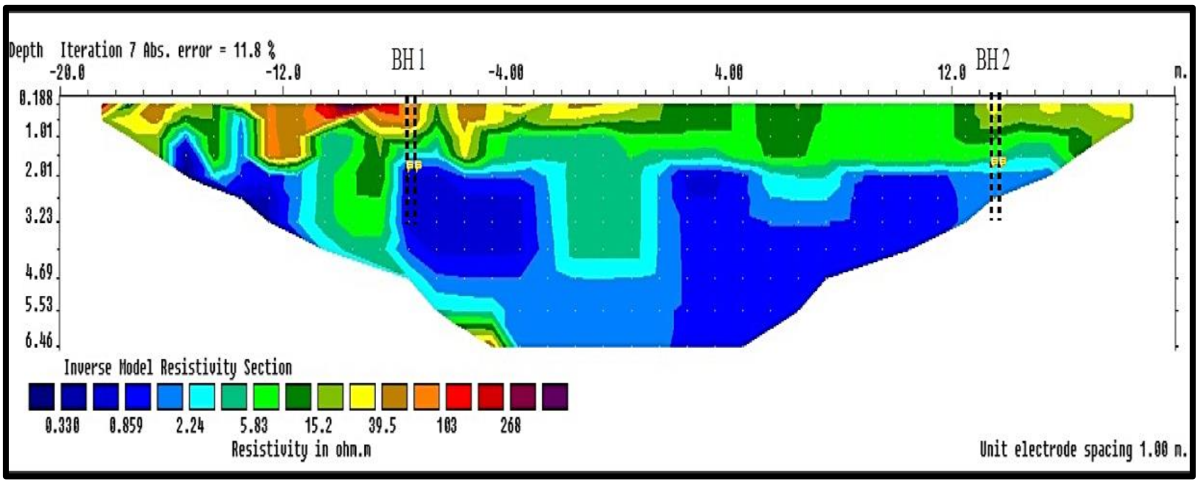
Seismic Converted to N-Value



2D Apparent Electrical Resistivity

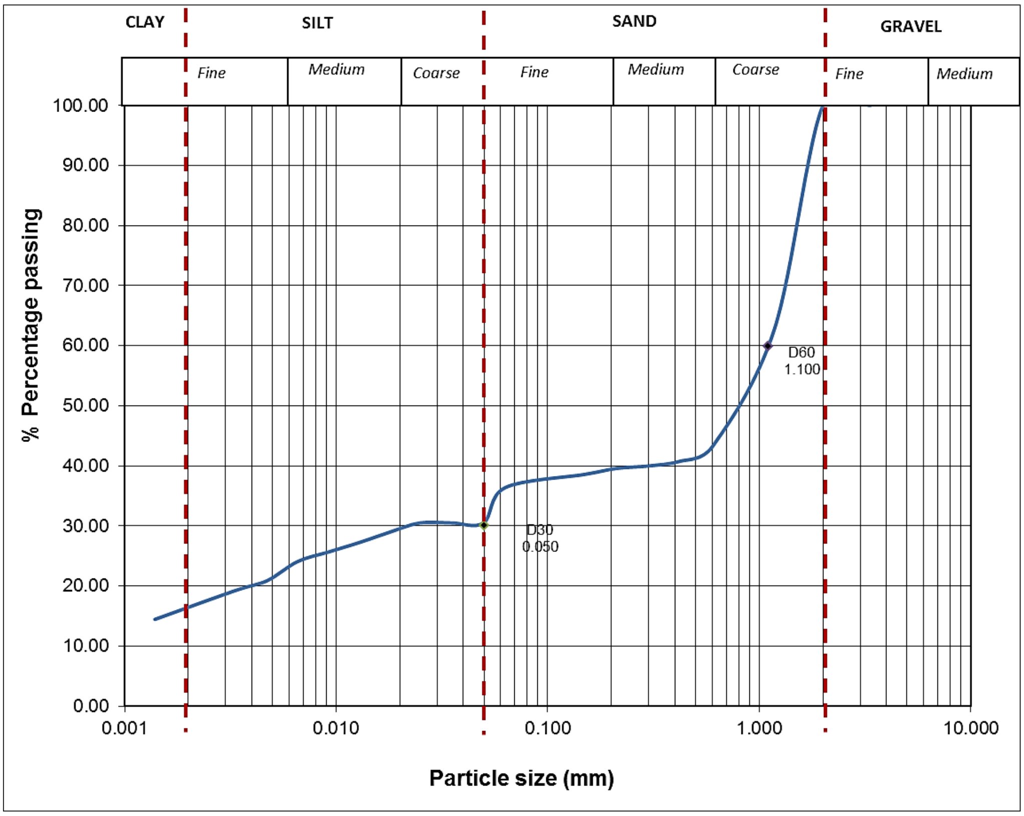


2D Inverted Electrical Resistivity

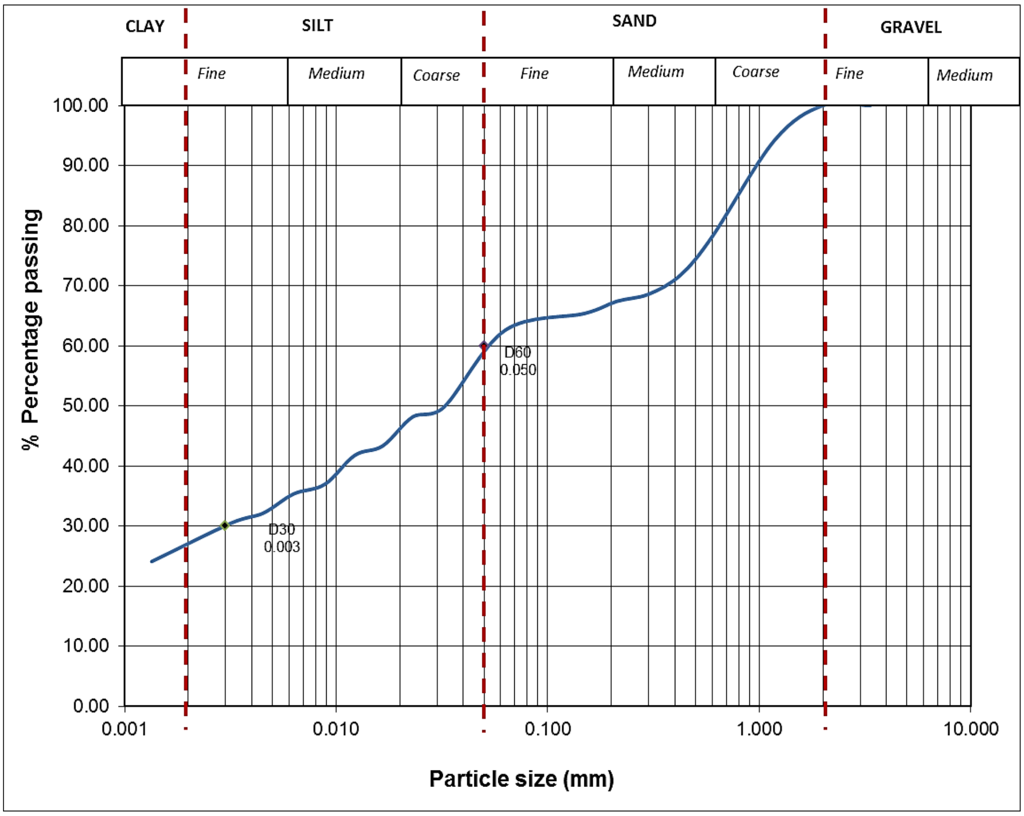


Particle Size Distribution

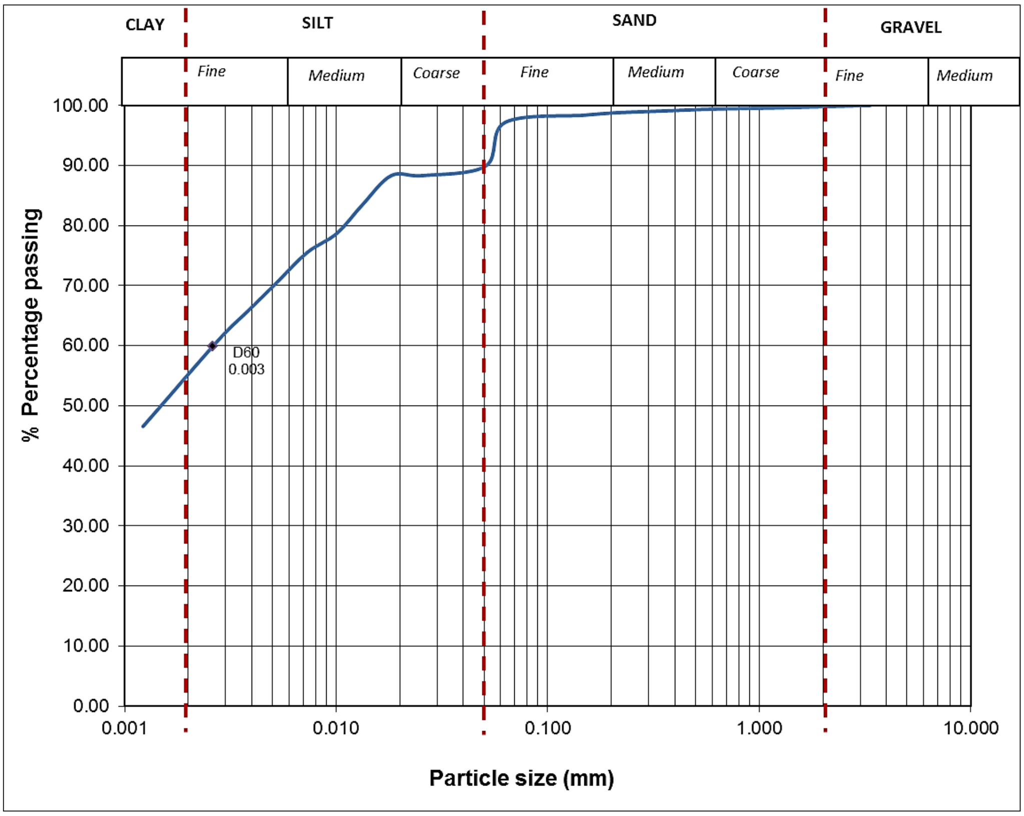
BH1-(1m)



BH1-(2m)

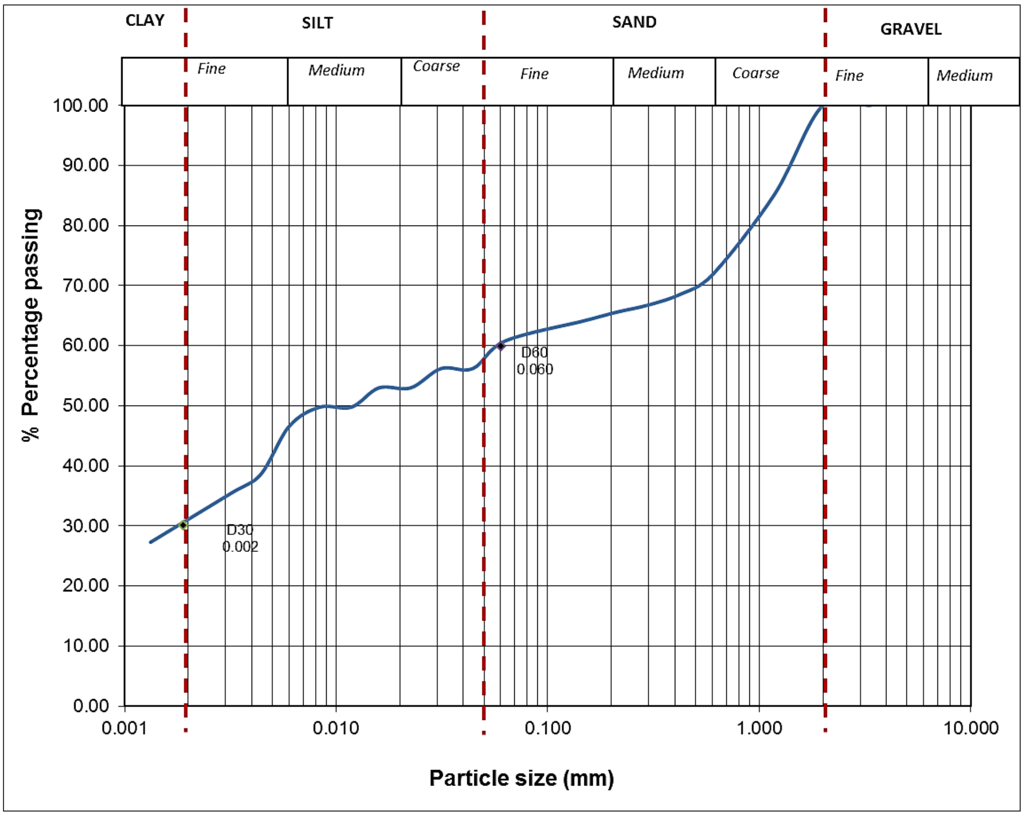


BH2-(3m)



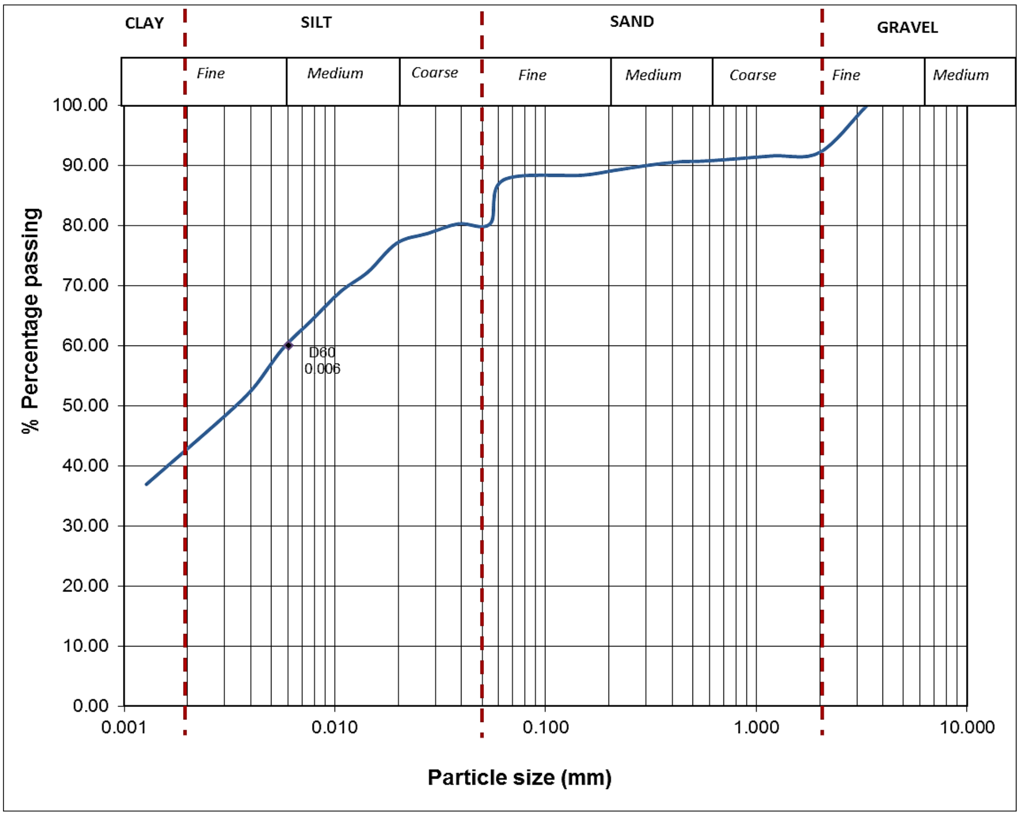
CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Percentage passing
D60
0.003
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

BH2-(1m)



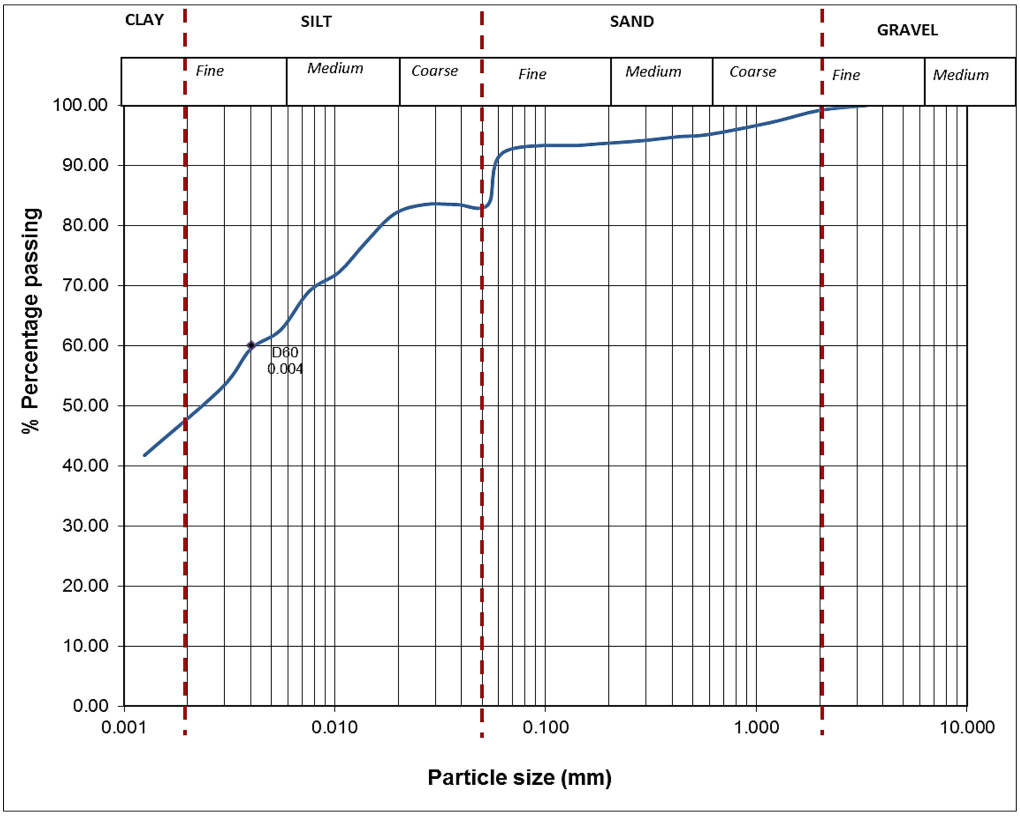
CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Percentage passing
D60
0.060
D30
0.002
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

BH2-(2m)



CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
% Percentage passing
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
D60
0.006
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

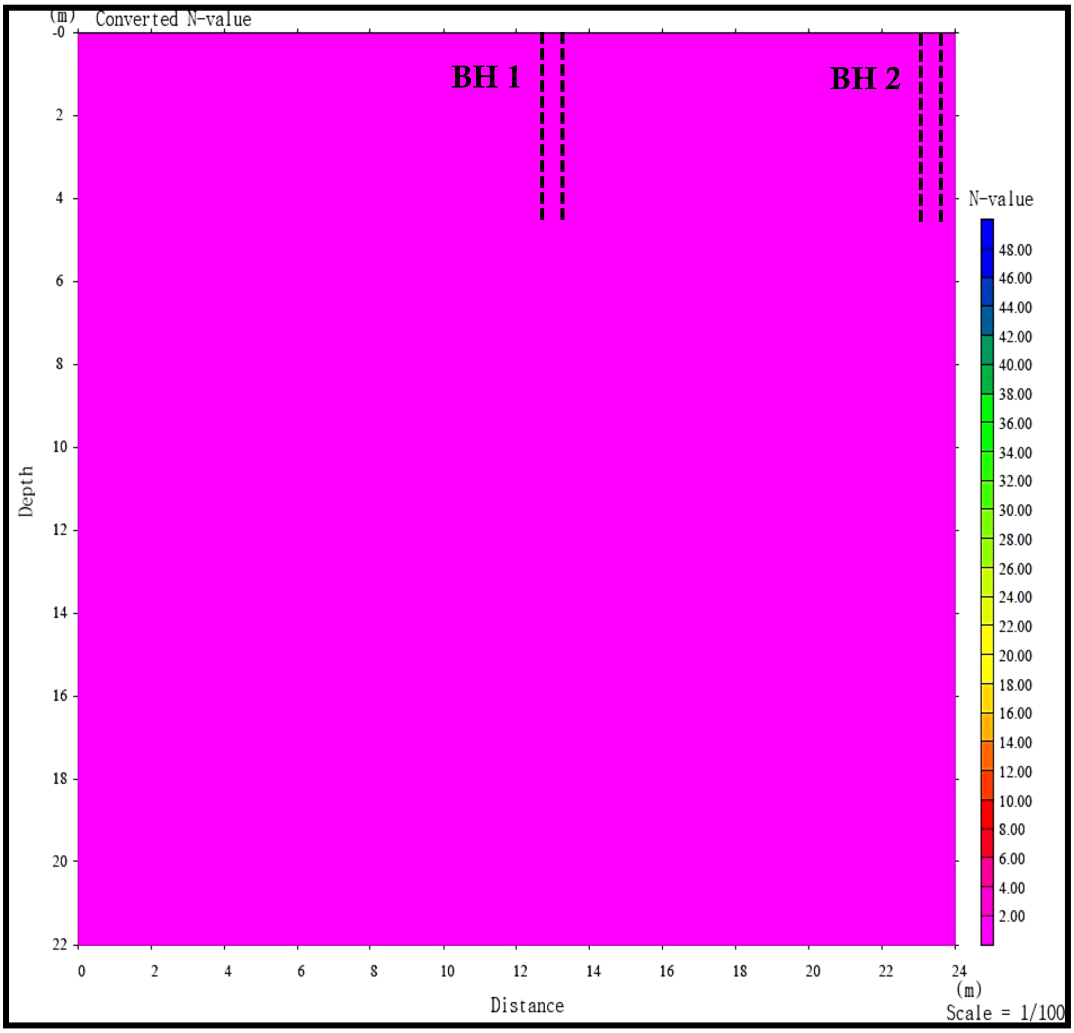
BH2-(3m)



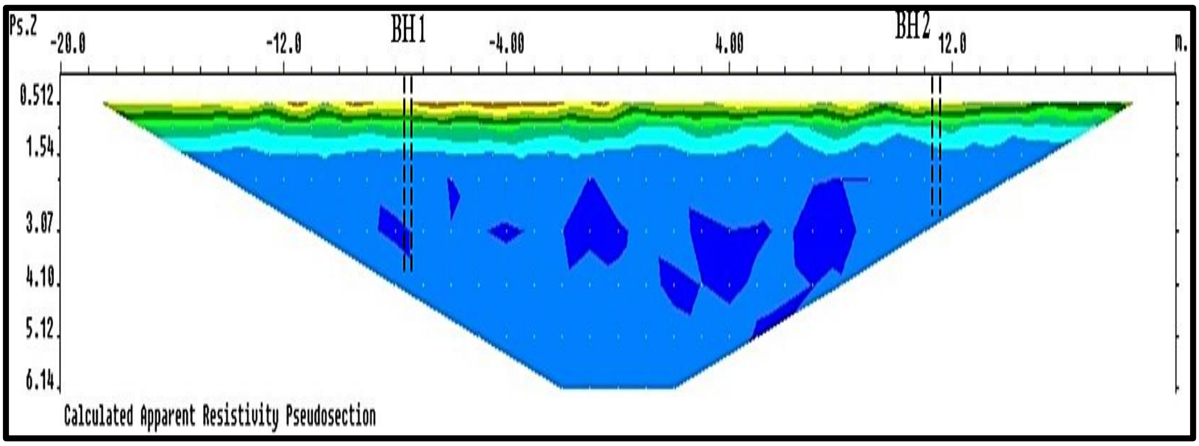
CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
% Percentage passing
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
D60
0.004
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

Location: Perlis

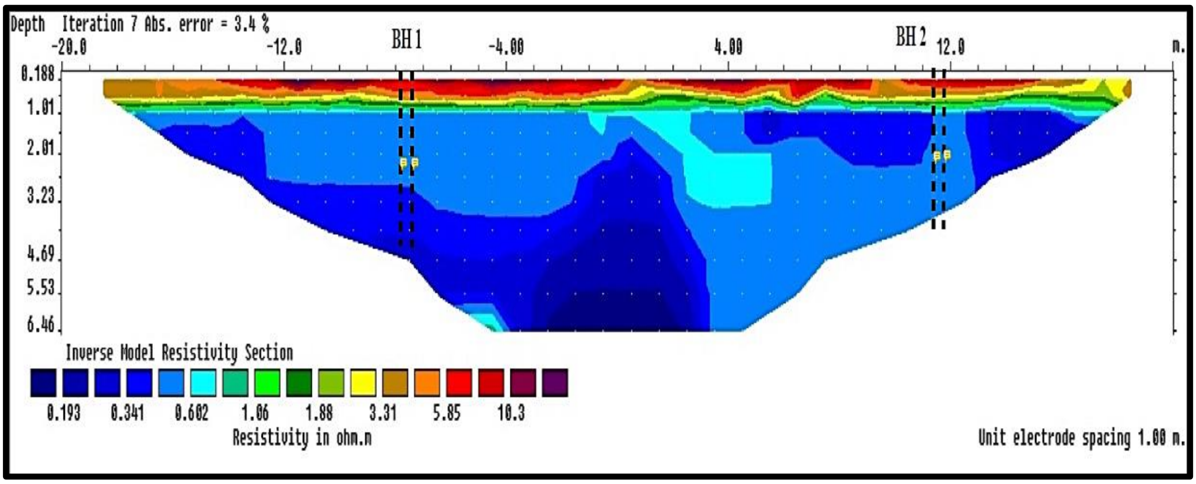
Seismic Converted to N-Value



2D Apparent Electrical Resistivity

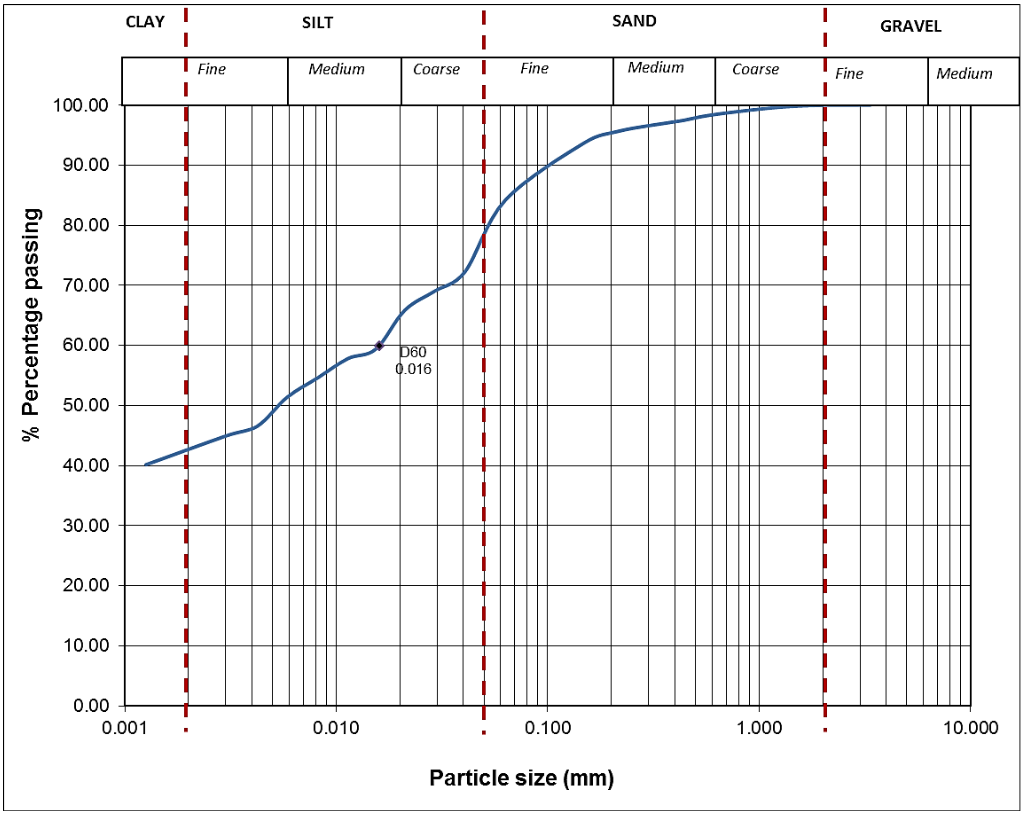


2D Inverted Electrical Resistivity

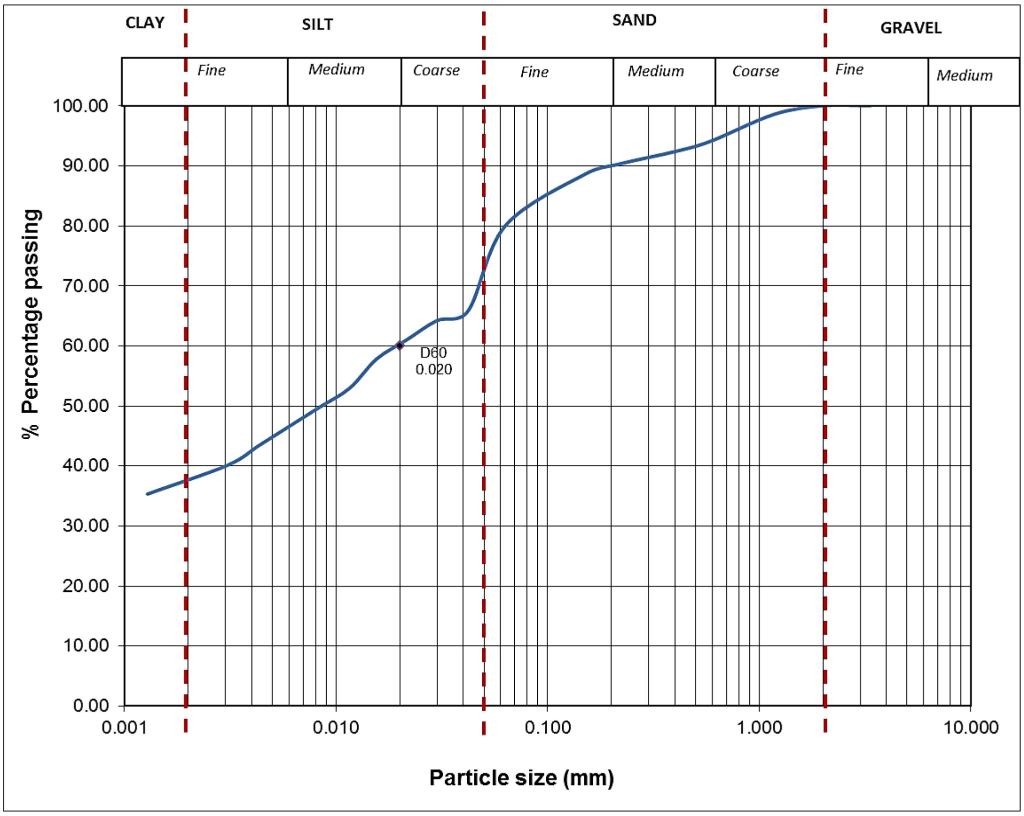


Particle Size Distribution

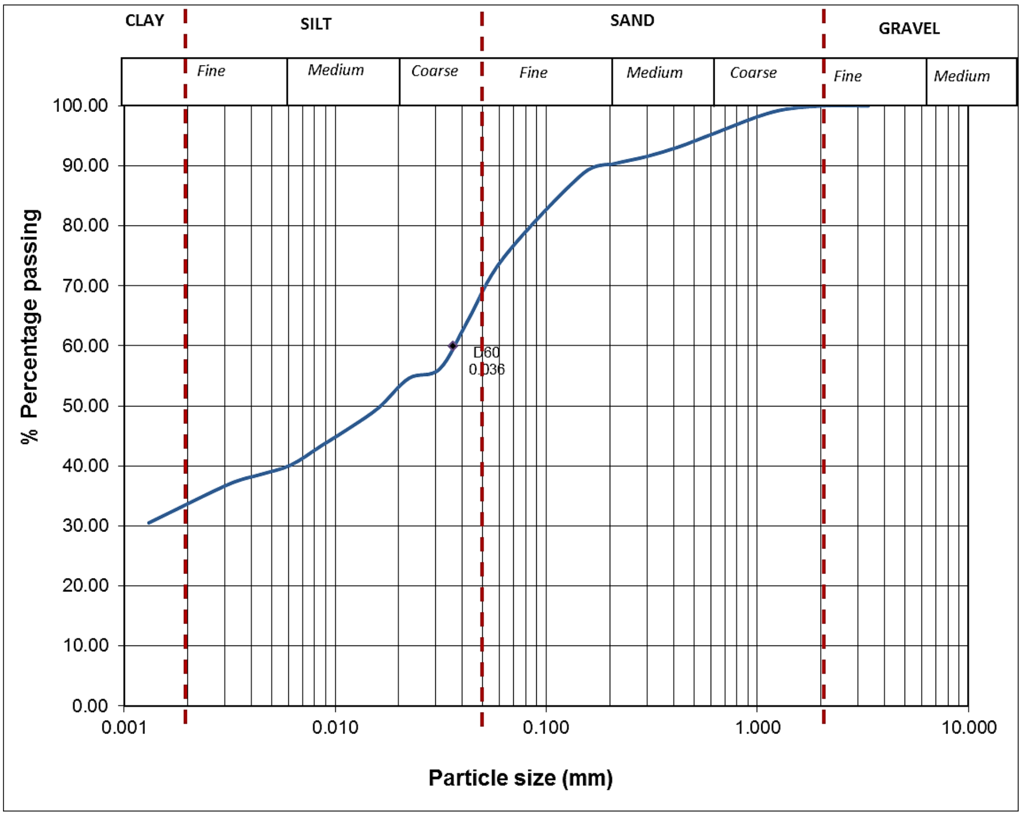
BH1-(1m)



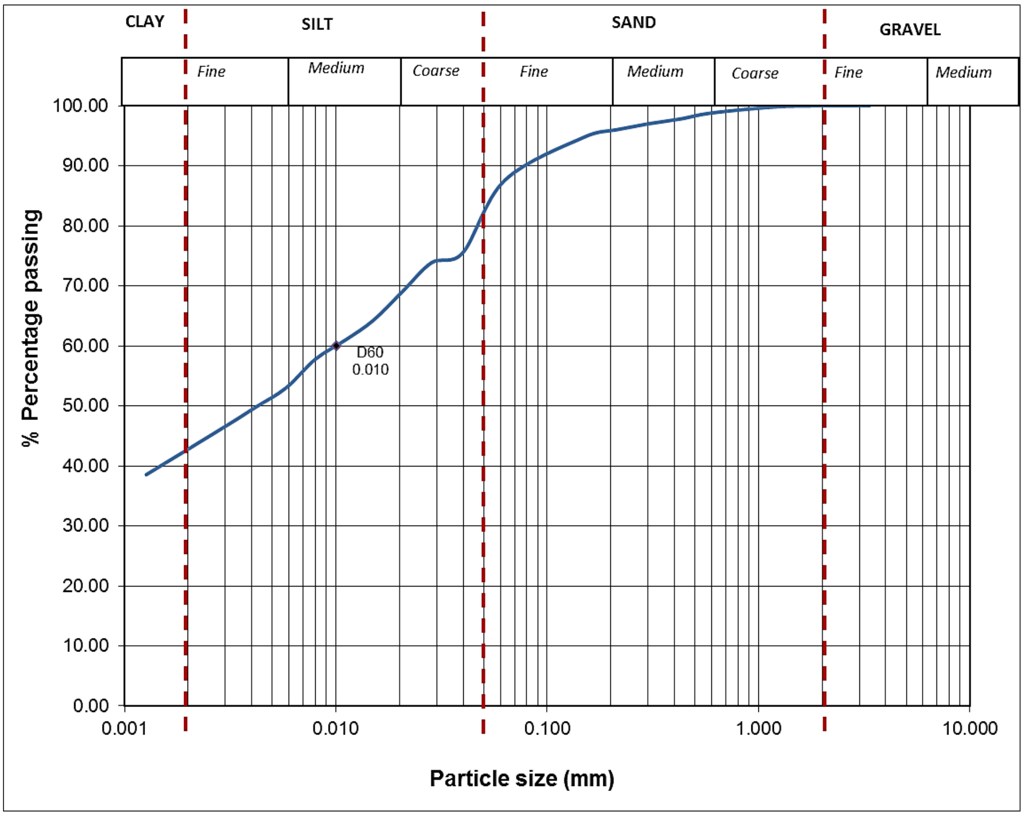
BH1-(2m)



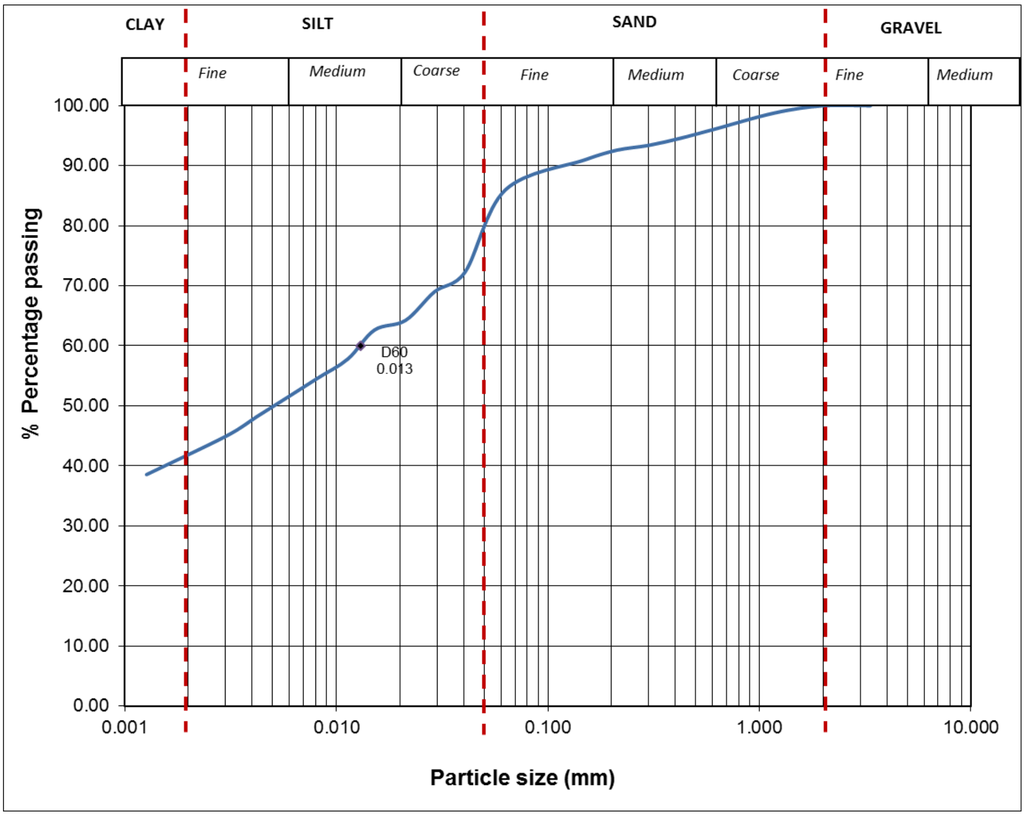
BH1-(3m)


CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Percentage passing
D60
0.036
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

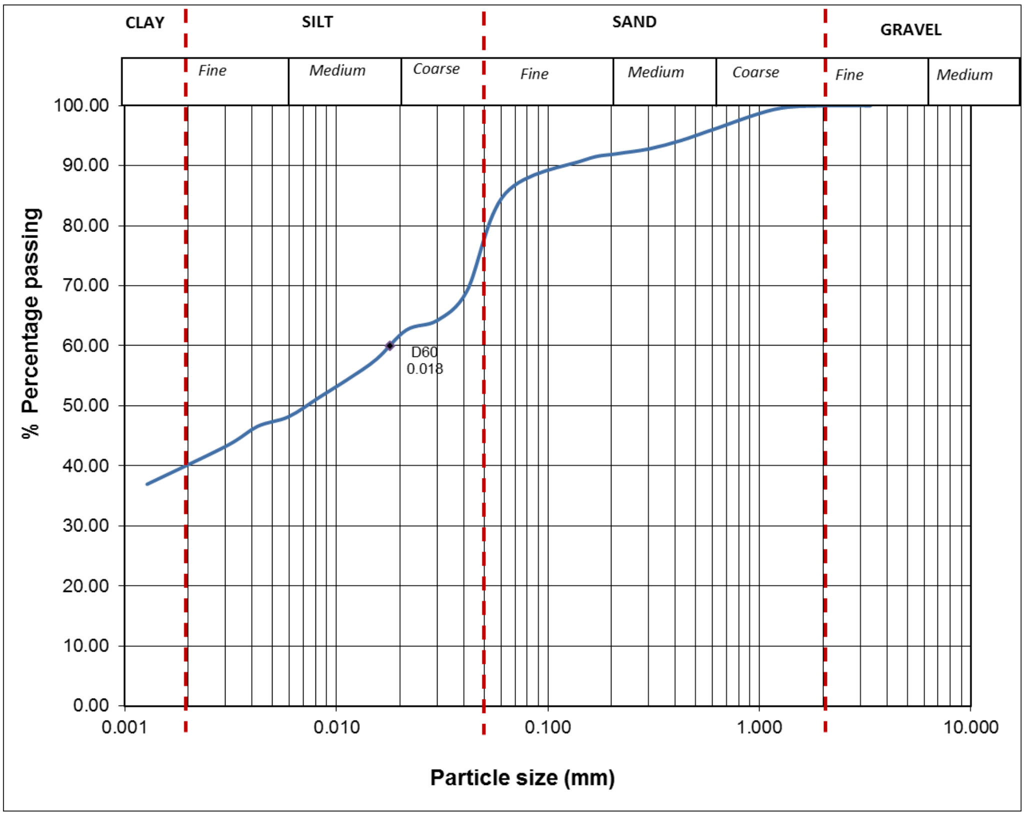
BH2-(1m)


CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Percentage passing
D60
0.010
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

BH2-(2m)

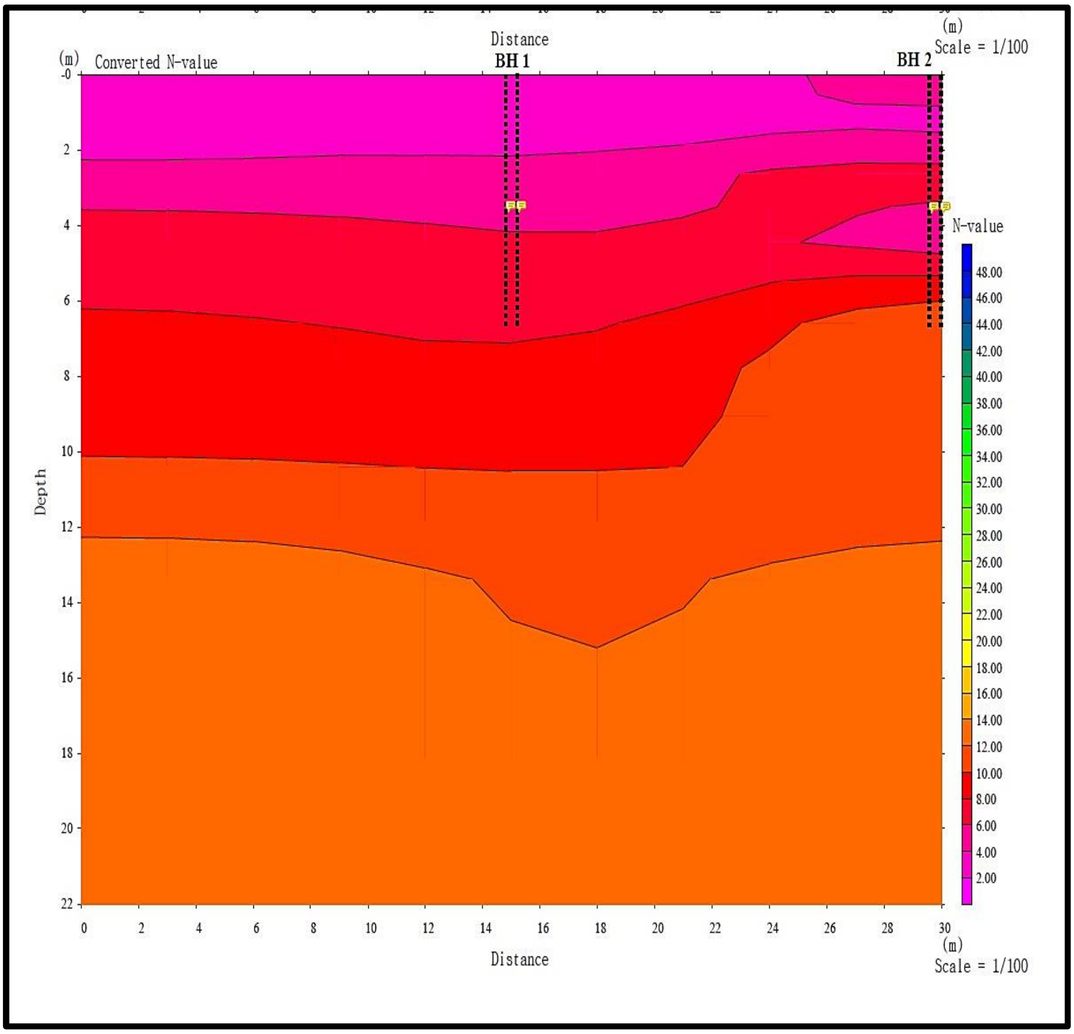

CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
% Percentage passing
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
D60
0.013
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

BH2-(3m)

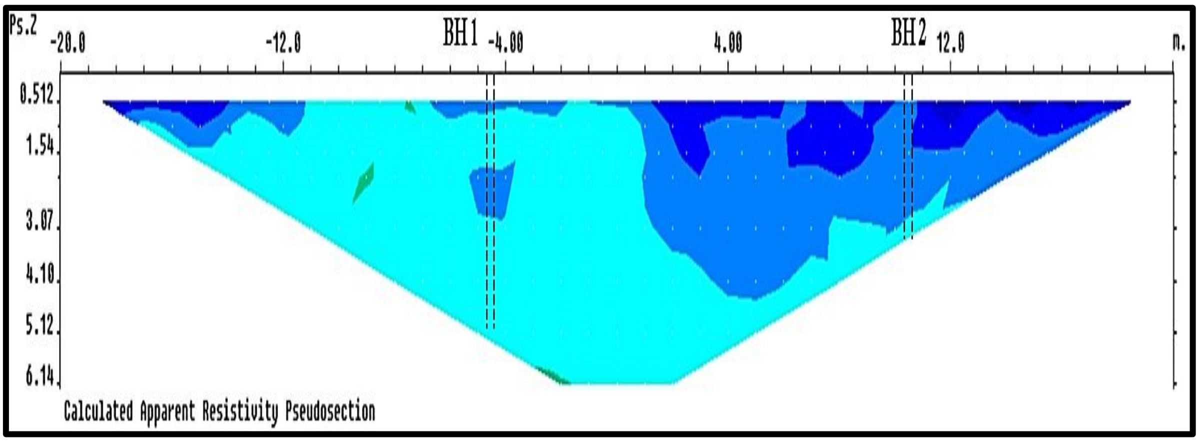

CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
% Percentage passing
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
D60
0.018
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

Location: Cameron Highland

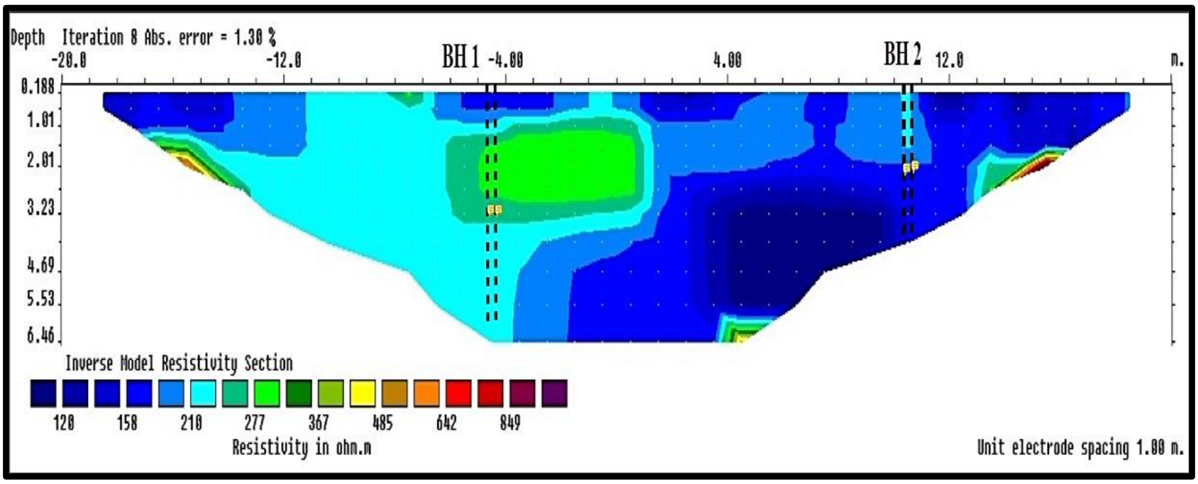
Seismic Converted to N-Value



2D Apparent Electrical Resistivity

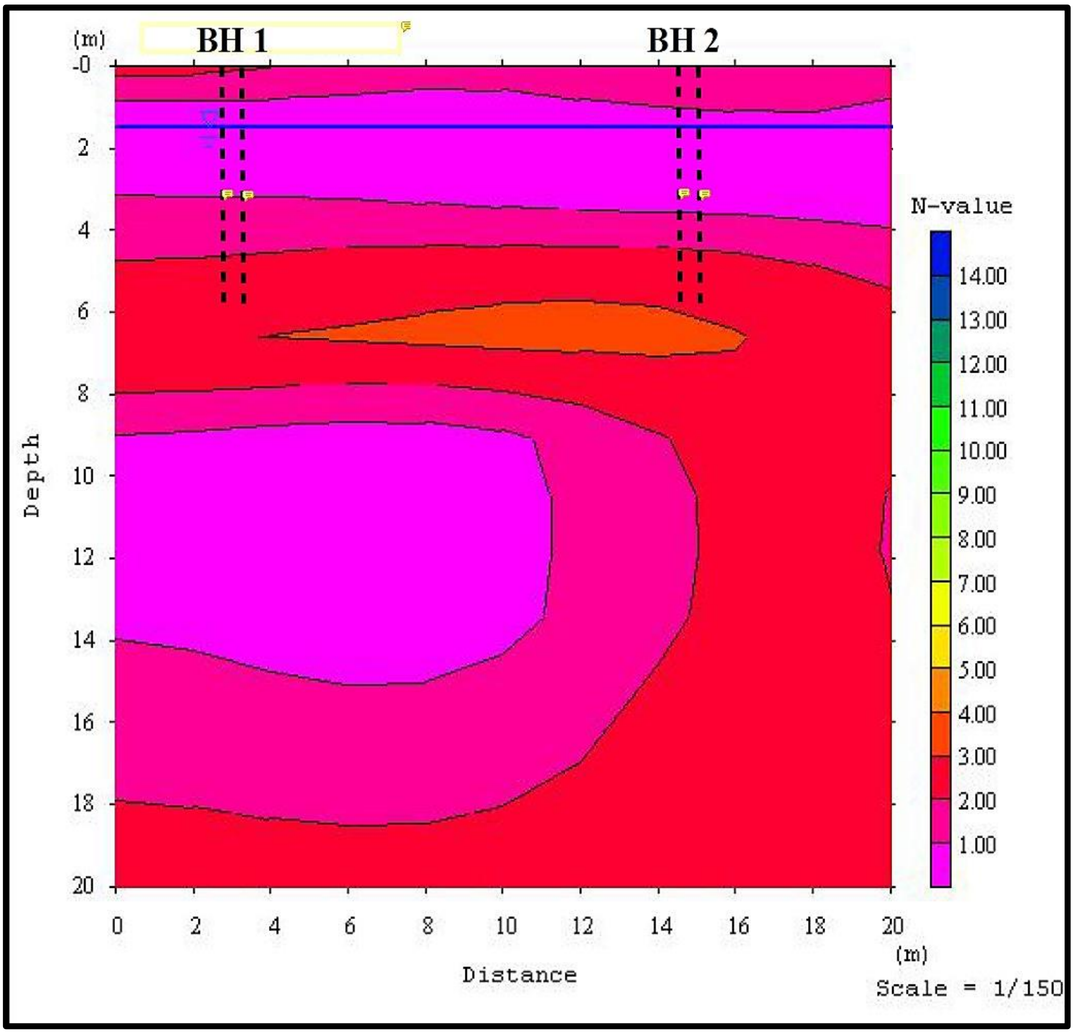


2D Inverted Electrical Resistivity

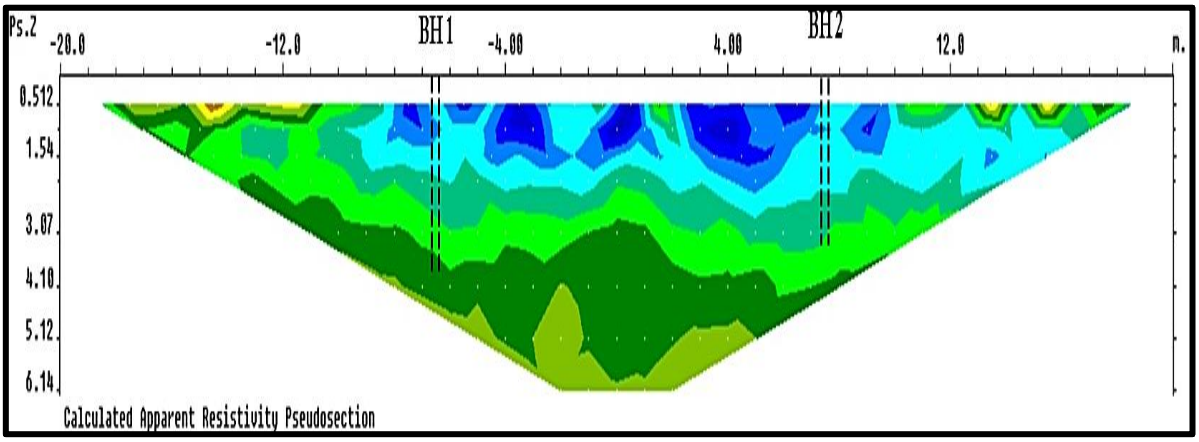


Location: Pekan

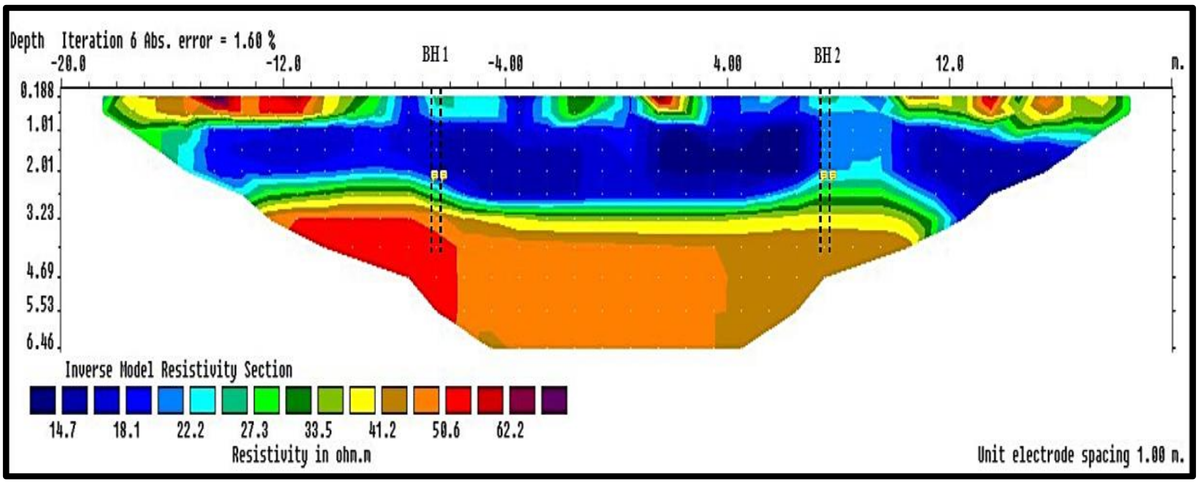
Seismic Converted to N-Value



2D Apparent Electrical Resistivity

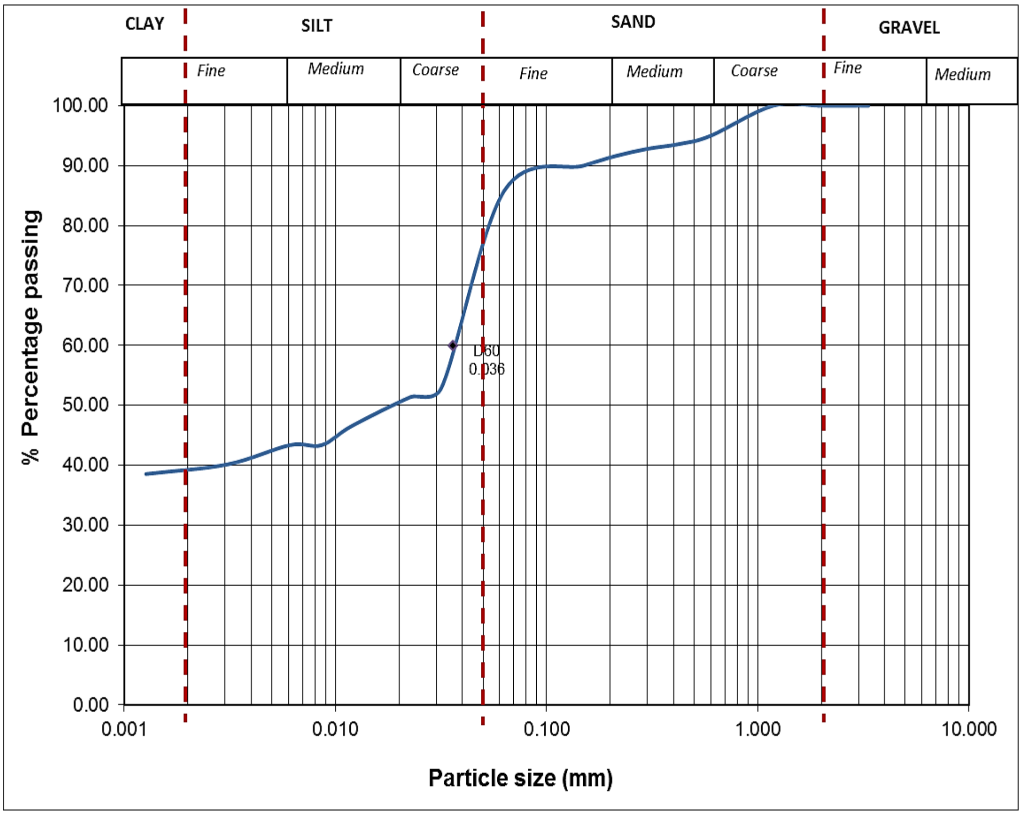


2D Inverted Electrical Resistivity

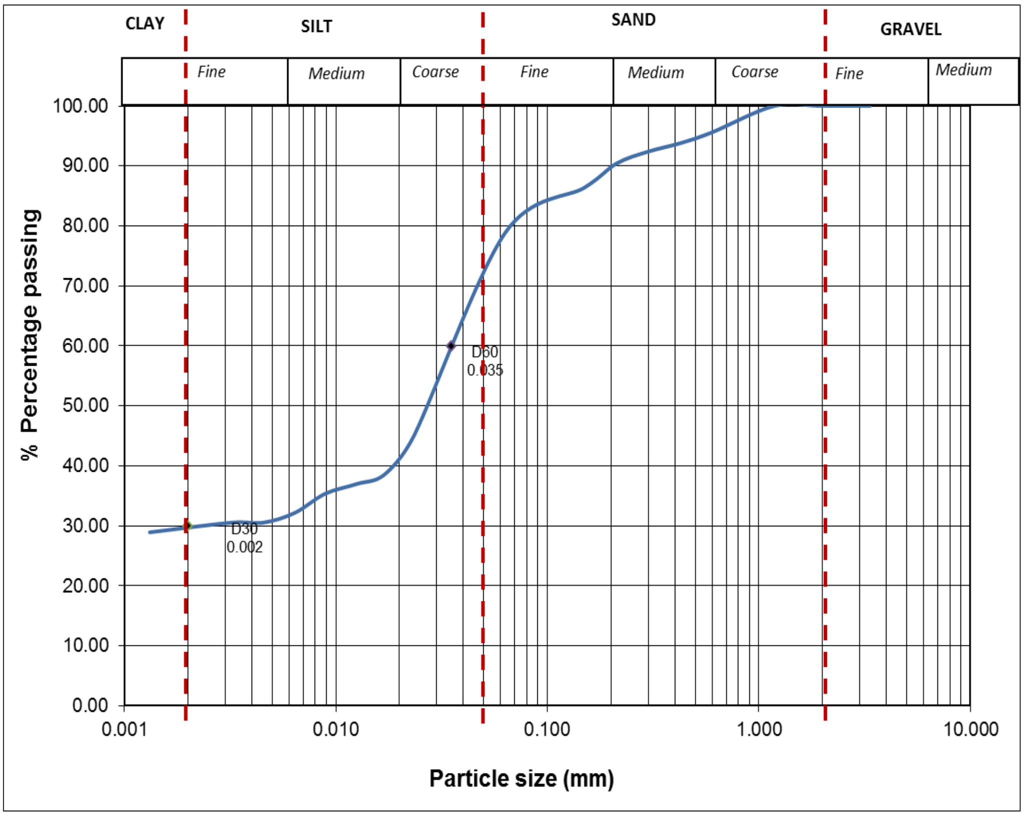


Particle Size Distribution

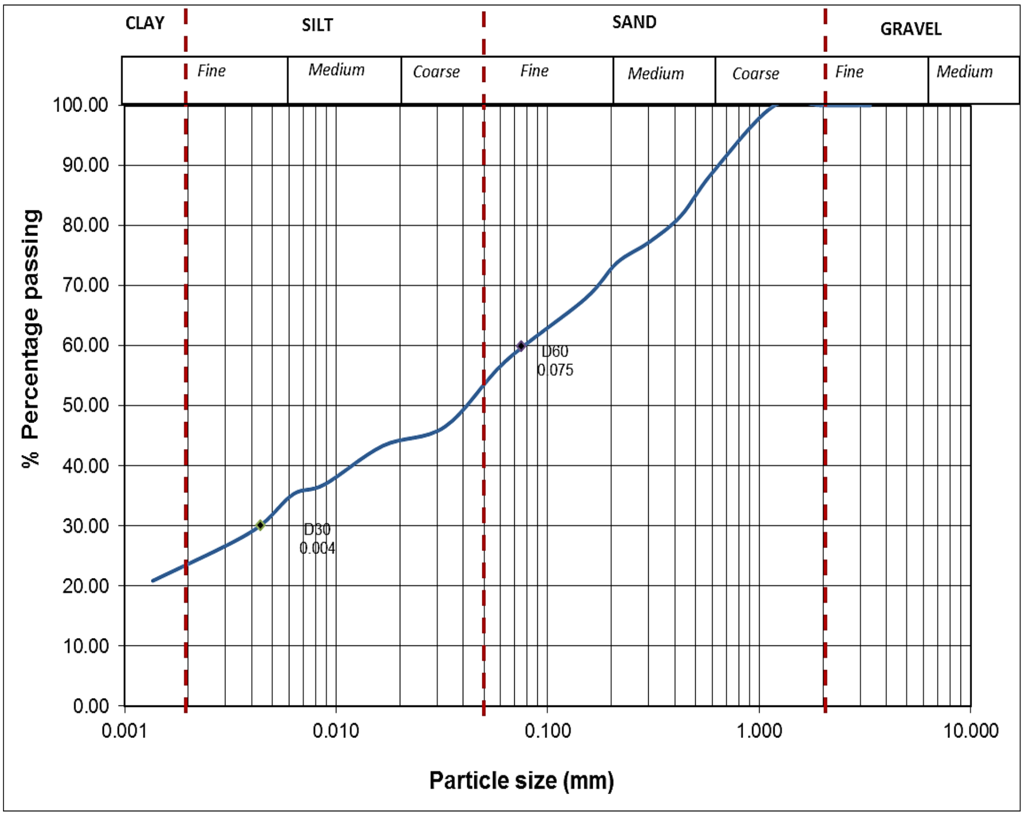
BH1-(1m)



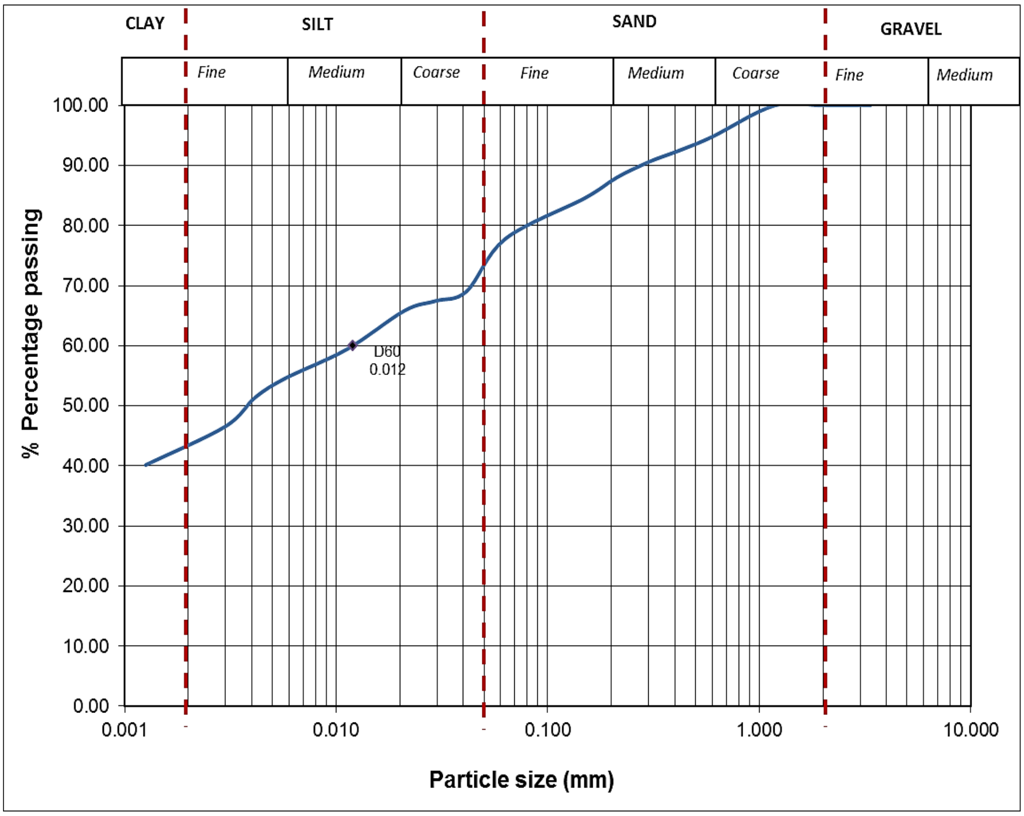
BH1-(2m)



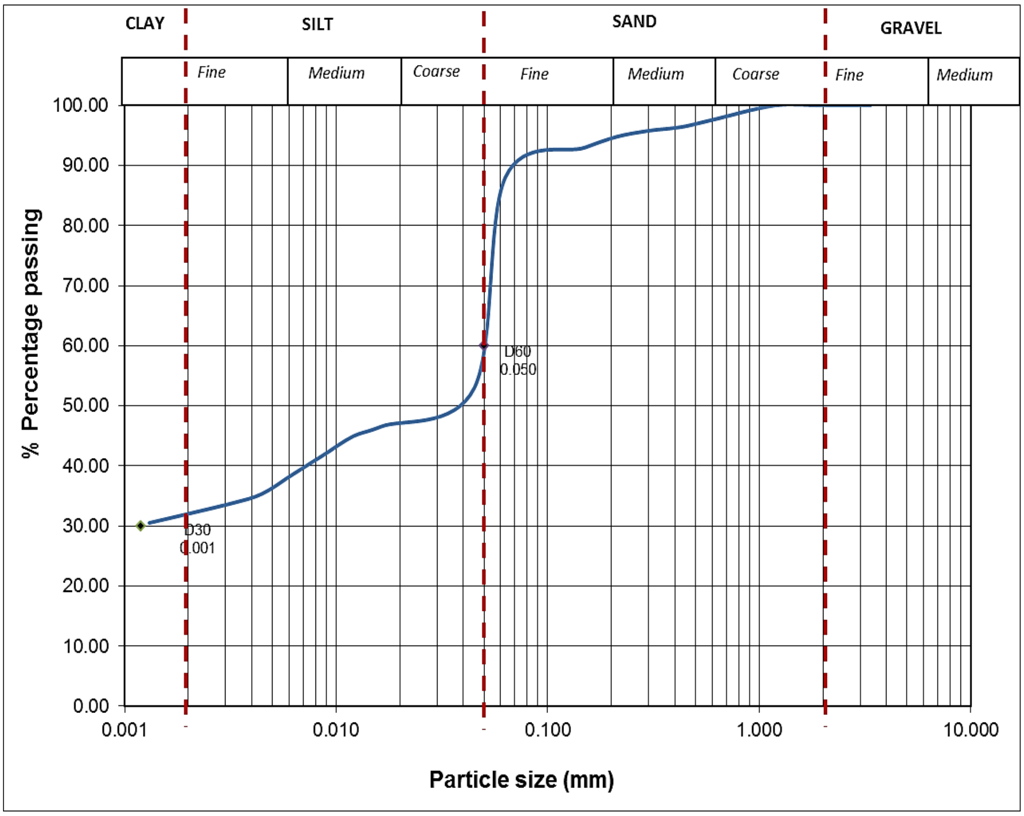
BH1-(3m)


CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Percentage passing
D60
0.075
D30
0.004
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

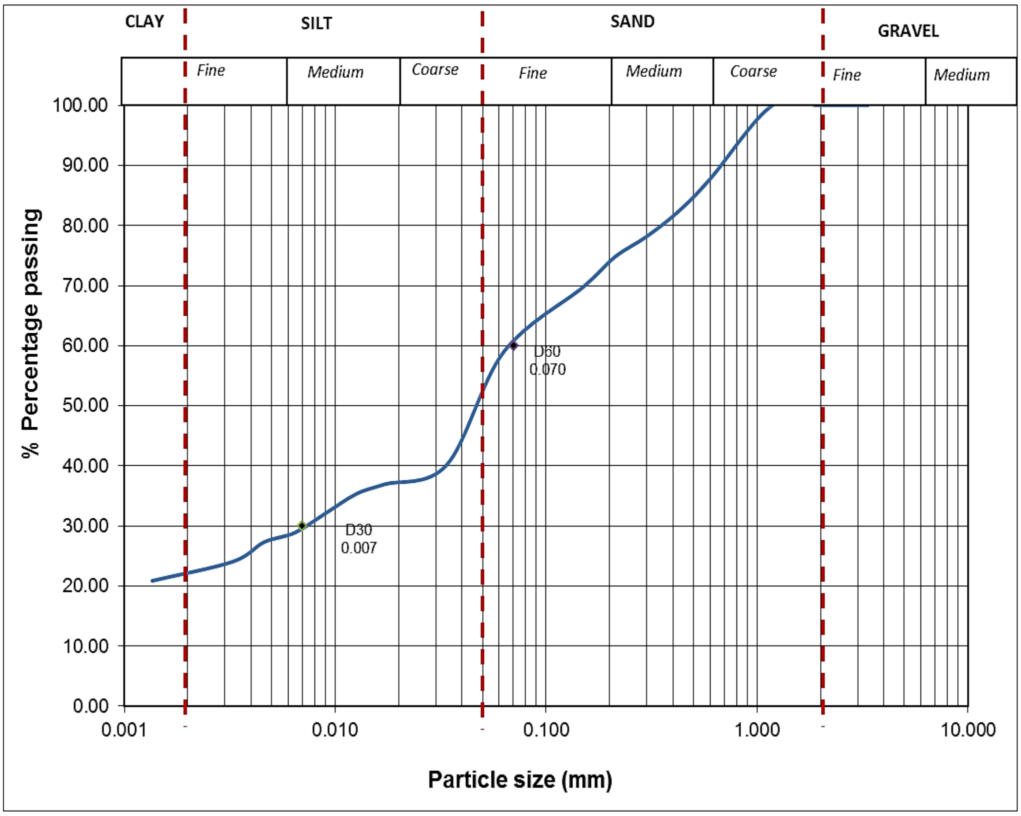
BH2-(1m)


CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Percentage passing
D60
0.012
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

BH2-(2m)

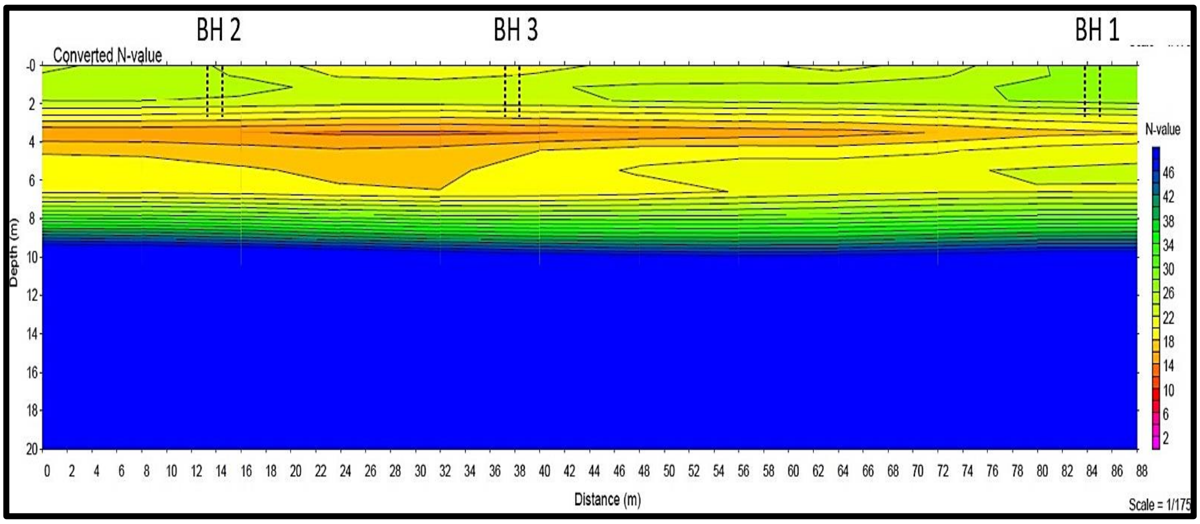

CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Percentage passing
D60
0.050
D30
0.001
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

BH2-(3m)

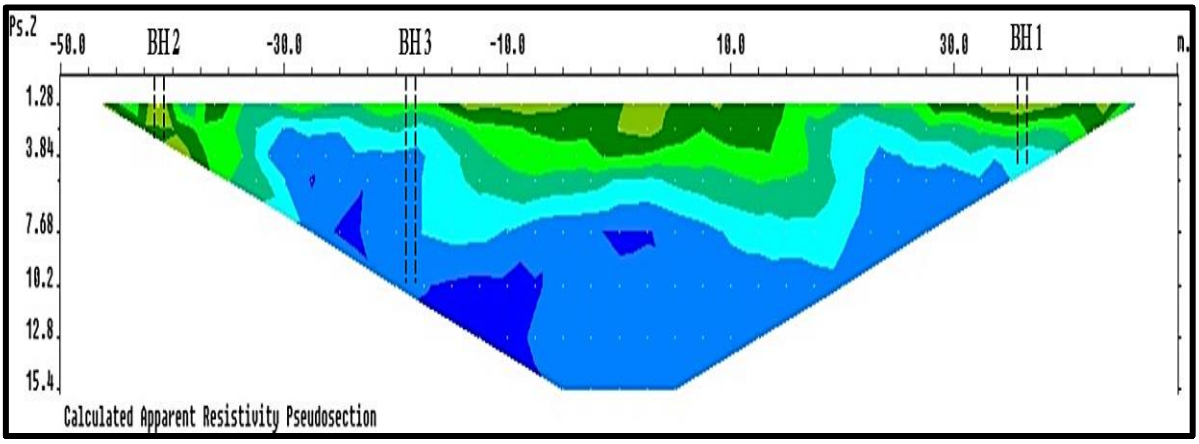

CLAY
SILT
SAND
GRAVEL
Fine
Medium
Coarse
Fine
Medium
Coarse
Fine
Medium
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Percentage passing
D60
0.070
D30
0.007
0.001
0.010
0.100
1.000
10.000
Particle size (mm)

Location: UTP (Line 1)

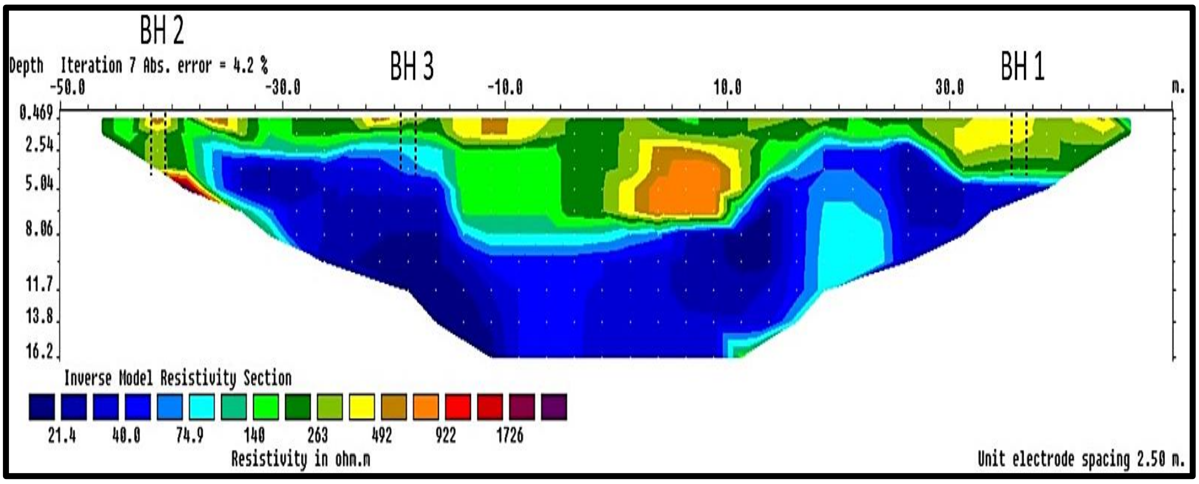
Seismic Converted to N-Value



2D Apparent Electrical Resistivity

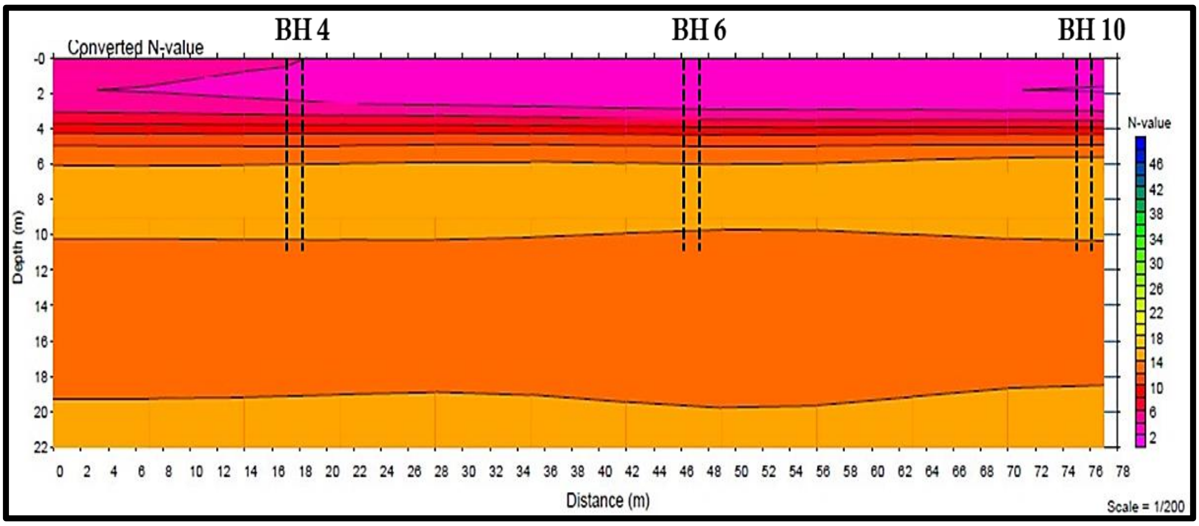


2D Inverted Electrical Resistivity

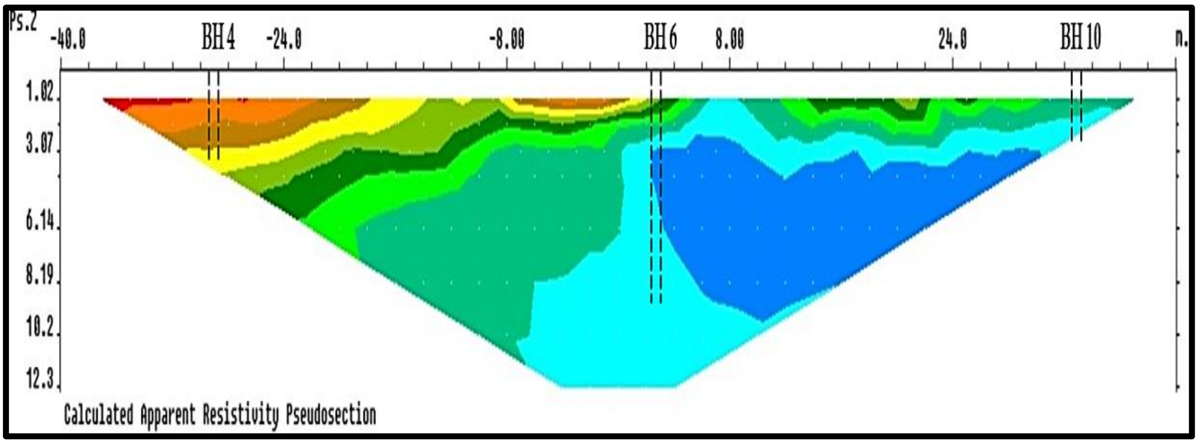


Location: UTP (Line 2)

Seismic Converted to N-Value



2D Apparent Electrical Resistivity



2D Inverted Electrical Resistivity